MECHANICAL DRAFT

J. H. KINEALY

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MECHANICAL DRAFT

A PRACTICAL HANDBOOK

FOR

ENGINEERS AND DRAFTSMEN

BY

J. H. KINEALY,

Formerly Professor of Mechanical Engineering at Washington University; Member American Society of Mechanical Engineers; Member Society of Arts, England; Past-President American Society of Heating and Ventilating Engineers; Past-President Engineers Club of St. Louis; Fellow American Association for the Advancement of Science; etc., etc.

WITH TWENTY-SEVEN ORIGINAL TABLES

AND

THIRTEEN HALF-TONE PLATES

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PREFACE.

In writing this little book the author has assumed that those who will use it are familiar with boiler and engine plants, and he has had in mind the practicing engineer who is called upon to design power plants, and who must therefore decide when it is best to use some form of mechanical draft. The arrangement of the book is what the experience of the author in making calculations for mechanical draft installations has shown him is probably the best. And he has tried to arrange the tables in such a way and in such a sequence that they may prove as useful to others as they have to him.

With the exception of such tables and matter as has been taken from the author's book on Centrifugal Fans, all of the tables that are to be used in designing a mechanical draft plant are new and have been calculated especially for this work. Tables have been used liberally because

they have been made for the conditions which generally occur in actual practice and because they decrease so enormously the labor of designing a plant. In all cases, however, the formulas used in calculating the tables have been given, so that for all those conditions that are beyond the range of the tables, engineers may make their own calculations.

While the book is intended primarily for the practicing engineer, full explanations of the various steps leading up to the finished design of a mechanical draft apparatus have been given with the hope that the book may prove of value as a text-book for young engineers and students. The author can call to mind no book which even attempts to discuss the subject of mechanical draft in such a way as to enable a student to get any idea as to the steps to be followed in designing a mechanical draft apparatus so that it will give certain predetermined results under given fixed conditions, and he is led, therefore, to hope that the book will find favor with the teachers of engineering as well as with their students and the older practicing engineers.

The method of treatment is new, the equations are new, the tables are new; and the book is a monograph representing years of study and work

on the part of the author. And last but not least is the fact that the book has been *written* and has not been made from the books of others by a free use of the scissors.

The author has striven to add something to the sum total of the engineering knowledge of the world, and if he has been able to do this he will not consider that his efforts have been in vain.

The author desires to express his thanks to The Green Fuel Economizer Co., The American Blower Co., B. F. Sturtevant Co., and the Niagara Radiator Co., for their kindness in supplying the photographs used for most of the illustrations.

J. H. KINEALY.

February, 1906.
St. Louis, Mo.

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CHAPTER I.

GENERAL DISCUSSION.

Introduction. When laying out a power plant the engineer must determine the draft necessary to burn the required amount of fuel per hour, and also how this draft shall be created, whether it shall be natural or artificial. A draft is said to be natural or chimney draft when it is due to the difference between the density of the cold air on the outside of a chimney and that of the hot products of combustion passing upward on the inside, and a draft is said to be artificial when it is produced artificially by means of a jet of steam or some form of blower or fan.

If the draft is produced by some form of fan or blower it is said to be mechanical draft.

The draft produced by a chimney depends upon the height of the chimney, the temperature of the hot gases inside, and the temperature of the cold air outside. It may be affected by the direction and velocity of the wind, and by the

humidity of the outside air, but as the influence of either of these is usually small they are always neglected when designing a power plant. When the draft is expressed in inches of water it is found that the draft created by a chimney varies, according to the temperature of the hot gases and that of the air outside, from 0.005 to 0.007 times the height of the chimney in feet. The temperature of the gases passing out through a chimney is greater at the base than at the top, and it is the average temperature which determines the draft which will be created for a given height of chimney and a given outside temperature. As it is practically impossible to measure the temperature of the gases at different points from the base to the top, it is impossible to determine the average temperature of the gases in a chimney. The temperature of the gases in a chimney is always measured near the base, sometimes in the chimney itself and other times in the uptake or breaching between the boiler and the chimney. The higher the chimney the greater is the fall of temperature as the gases pass upward, and hence the less is the average temperature of the gases in the chimney, and, therefore, the greater is the difference between the draft actually created and the draft calculated upon the supposition that the

temperature at the base is the average temperature. Since the cooling of the gases passing upward is greater in a steel or an iron chimney than in a thick, heavy brick chimney, the draft created by a steel or an iron chimney is in general less for a given temperature of the gases at the base and a given temperature of the outside air, than for a brick chimney of the same height.

The temperature of the gases measured at the base of a chimney varies from 350 to 600 degrees Fahrenheit, for the usual boiler plant without economizers or an air heater in the breeching. Of the heat carried up the chimney by the escaping gases, only that which is not necessary to produce the required draft can be said to be lost; the rest is used in creating the draft, and thus serves an exceedingly useful purpose.

Steam jets for the creation of an artificial draft are used on all locomotives, many launches and small boats, and to a limited extent only on power plants. As used on power plants, the steam jet serves usually for introducing a supply of air above the grate bars; and is generally used more for reducing the amount of smoke by serving to mix up and bring about a more complete mingling of the hot gases and air in the furnace than for increasing the draft.

Mechanical draft is used on almost all large steam-ships and to a considerable extent in power plants on land. It is used in almost all cases, except on locomotives and launches, where it is necessary to have a high draft, and its use in connection with power plants both large and small is increasing daily. The form of blower used is almost invariably the ordinary centrifugal fan, and the draft which can be created depends almost entirely upon the velocity in feet per minute of the periphery of the blades. So that by running the fan fast or slow the draft may be increased or decreased at will, and thus be made to suit the particular requirements of the plant at any time.

Systems of Mechanical Draft. Mechanical draft is subdivided into two systems according to whether the air is made to enter the furnace by reducing the pressure at some point beyond the boiler so as to make it less than atmospheric pressure and thus suck the air into the furnace, or whether the air is forced into the furnace under a pressure slightly greater than that of the atmosphere. When the air is sucked into the furnace and enters under atmospheric pressure, the system is called an "induced draft system";

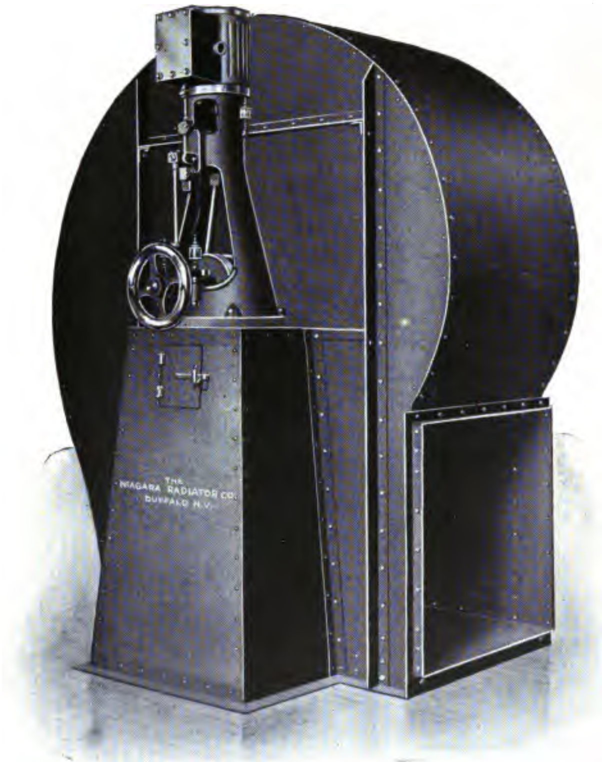

FIG. 1.—BOTTOM, HORIZONTAL DISCHARGE FAN.
(Niagara Radiator Co.)

and when the air is forced into the furnace, the system is called a " forced draft system."

The same kind of fan is used for both systems, but the details of the two systems differ in many respects, and it often happens that one is much more suitable for certain conditions than the other. Except in connection with certain types of patented mechanical stokers, the forced draft system is not used as much with power plants as the induced draft system, while on steam-ships the forced system is used almost entirely to the complete exclusion of the induced system.

Chimney vs. Mechanical Draft. It is probable that after considering this question the engineer will find that the real decision must be between chimney or natural draft and mechanical draft; and as the mechanical systems of draft are newer and less tried than the chimney draft, he will look for the advantages which it is claimed mechanical draft has over chimney draft and weigh them with the disadvantages.

In comparing chimney with mechanical draft the practical engineer would be likely to consider each under the following heads:

1.— Liability to derangement.
2.— First cost.

3.— Depreciation and repairs.
4.— Running expenses.
5.— Economy in operation of plant.
6.— Provision for future increase of plant.

Liability to Derangement. As far as liability to derangement is concerned, every engineer knows that there is nothing about a chimney to get out of order, no machinery of any kind and no moving parts, and the only way a chimney can be put out of service is for it to fall. Thin, guyed, sheet steel chimneys rust out quite rapidly and then are easily blown over; self-supporting steel chimneys, either lined or unlined, usually have a much longer life, the length of which depends naturally upon the thickness of the metal of which they are made and the care given to them; brick or stone chimneys when well built last practically forever, and when properly designed and erected do not fall unless struck by lightning or a cyclone. A mechanical draft apparatus, however, always comprises in addition to the fan or blower a motor of some kind for driving the fan or blower; so that there are many moving parts, any one of which is liable to give trouble. In fact, a mechanical draft apparatus is a machine, liable to all the accidents and ills of a simple machine; and because of this fact

it is necessary, when the draft depends entirely upon the mechanical draft apparatus and there is no chimney to fall back upon in case of an accident to the fan or its motor, to install duplicate fans and motors. When, however, there are duplicate fans and motors of the proper size, there is no more danger of a mechanical draft apparatus being put entirely out of service, or becoming so deranged as to cause a shutdown of the entire power plant than there is in the case of a chimney of brick or stone.

First Cost. It is extremely difficult to make a general comparison of the first cost of a chimney with that of a mechanical draft plant, because of the fact that most chimneys for power plants are usually put up with a view of obtaining a draft from 0.5 to 0.75 of an inch of water, while mechanical draft systems are seldom installed except to give a draft of not less than at least one inch. It is probable that most chimneys are between 100 and 150 feet high, while a chimney to give a draft of one inch would have to be between 175 and 200 feet high, and the cost of a chimney increases very much as the height is made greater than about 125 feet. Moreover, for a large power plant several small steel chimneys are

often put up instead of one large brick chimney, and these chimneys may be of cheap steel construction, so that the cost may be small. Again, there is the curious difference between a chimney and a mechanical draft apparatus, that while a tall chimney to give a high draft costs more than a low chimney to burn the same quantity of coal under a low draft, a fan to supply air for a given quantity of coal under a high draft costs less than a fan for the same quantity of coal under a low draft. A low draft, however, means a low rate of combustion per square foot of grate surface, and hence a large area of grate in order to burn a given quantity of coal per hour, and it means also an almost total inability to burn coals of very low grade; while a high draft means a rapid combustion per square foot of grate surface, and hence a small grate to burn a given quantity of coal per hour, and also the ability to burn cheap coals of low grade.

A chimney to give a draft of 0.75 of an inch must be about 125 feet high, and one to give a draft of 1.5 inches would probably have to be at least 250 feet high. The cost of the higher chimney would be so very much greater than that of the lower that few engineers would recommend it solely because of the greater draft

which could be obtained with it. In the case of a mechanical draft apparatus, however, the apparatus to supply the air for the combustion of a given quantity of coal per hour under a maximum draft of 0.75 of an inch would be larger and cost more than the apparatus to supply the air for the combustion of the same quantity of coal under a maximum draft of 1.5 inches. The diameter of the fan wheel for the higher draft would be only about 0.83 of the diameter of the fan wheel for the lower draft, and the dimensions of the engine, assuming it to be direct connected to the fan, might also be smaller for the higher draft. The work done in running the fan for the higher draft would be twice as great as that for the lower, and hence the running expenses would be almost twice as great, but even then the running expenses would be small. Thus to supply air for the combustion of 5,000 pounds of coal per hour with an economizer under a maximum draft of 0.75 of an inch of water, an induced mechanical draft apparatus would require a fan with a 7-foot wheel; while to supply air for the combustion of the same quantity of coal under a maximum draft of 1.5 inches a fan with a wheel 6 feet in diameter would be more than ample and a 5½-foot wheel would be almost large enough.

The 7-foot fan would have to be run at a speed of 195 to 200 revolutions per minute and would require a direct connected engine having a cylinder 6 inches in diameter with an 8-inch stroke; while the 6-foot fan would have to be run at a speed of about 325 revolutions per minute, and an engine having a cylinder 6 inches in diameter and an 8-inch stroke would be more than ample for it, because of the greater number of revolutions made per minute. The dimensions of the engine are based upon the supposition that the boiler pressure would be at least 100 pounds. This example illustrates the curious anomaly in regard to the difference between a chimney and a mechanical draft plant. In the case of the chimney the consideration of first cost makes the engineer keep the chimney as low as possible and get along with as low a draft as possible; while in the case of a mechanical draft apparatus the consideration of first cost makes the engineer keep the draft as high as possible. The running expense is what makes the engineer keep the draft given by a mechanical draft apparatus low, but this running expense is usually more than offset by such advantages as the ability to burn cheaper fuel and to maintain a hotter fire in the furnace, thus securing that more perfect combustion for

poor fuels which always attends a high draft. It is seldom that a mechanical draft system is installed to give a draft no greater than would be likely to be given by a chimney, and hence the higher draft capable of being obtained with the mechanical draft apparatus must be carefully borne in mind when considering the first cost. It is possible, of course, to put up one or more cheap chimneys for a power plant and make the cost of them less than the cost of a properly designed mechanical draft system, but it is probable that in most cases a lined, self-supporting steel chimney or a brick chimney will cost considerably more than a mechanical draft apparatus capable of furnishing air for the combustion of the same quantity of coal per hour, and further, capable of giving a higher draft than the chimney. When because of local conditions it is necessary to discharge the gases of combustion at a considerable height, 100 or 150 feet above the ground, the mechanical draft apparatus plus the chimney for the discharge of the gases may cost even more than a chimney alone that would be capable of furnishing at a low draft the air required for the combustion of the coal; but if the draft required be at all high, it is probable that even under these circumstances the cost of a suit-

able mechanical draft apparatus would be less than that of the chimney.

Depreciation and Repairs. The yearly sum to be set aside for depreciation and repairs for a brick chimney may be considered as nothing; while in the case of a fairly good sheet steel chimney, so thin as to require guys, it will probably be 15 or 20 per cent of the first cost; and for a self-supporting steel chimney it will depend entirely upon the thickness of the original metal and whether or not the chimney be lined. The depreciation and repairs of a mechanical draft system will be somewhere between 10 and 15 per cent of the first cost.

Running Expenses. The running expenses of a chimney are zero, and the running expenses of a mechanical draft plant include the cost of attendance, oil for lubricating the bearings of the motors and the fans, steam for supplying power to the motors, and, possibly in the case of an induced draft system, water for cooling the bearings of the fans. The attendance required is usually so little that its cost may be neglected as insignificant. In the case of a power plant using non-condensing engines and exhausting into the

atmosphere the water used for cooling the bearings of the fans of an induced draft apparatus may be run to the feed water heater and used as feed water; but when non-condensing engines are used and the exhaust is used for heating purposes and then returned to the feed water heater as water, or where condensing engines are used, the cost of the water used to cool the bearings of the fans of an induced draft system must be charged to the running expense of the apparatus. The steam used by the engine required to run a fan will of course depend upon the work the engine must do as well as the type of the engine. The work to be done depends upon the volume of air to be handled per minute and the maximum draft under which it must be moved. The engine is usually connected directly to the shaft of the fan and is not very efficient. For the fan with the 7-foot wheel, considered before, it would be necessary to use an engine which, if direct connected to the fan, would develop something less than 10 indicated horse-power when taking steam at about 100 pounds gauge pressure and making between 195 and 200 revolutions per minute, and would probably use between 400 and 500 pounds of steam per hour. The weight of steam which would be evaporated under actual

conditions by the combustion of the coal for which the fan would supply air would probably be between 30,000 and 40,000 pounds. That is the weight of steam used by the mechanical draft apparatus would be between 1 and 1.67 per cent of the steam generated by the plant. If the smaller fan, that is the one with the 6-foot wheel, were used and the air handled under a draft at the fan of 1.5 inches, the weight of steam used per hour would probably be between 2 and 3.5 per cent of the steam generated by the plant. Thus it is seen that the consideration of running expense tends to make the engineer adopt a low draft rather than a high one when designing a mechanical draft plant. It is probable that the steam used by the engine of a properly designed mechanical draft apparatus will seldom exceed 3 or 3.5 per cent of the total steam generated by the plant.

Economy in Operation of Plant. It is in the economy in the operation of the plant that a mechanical draft apparatus really makes its great showing. In the case of a chimney the draft depends upon the height of the chimney, the temperature of the hot gases inside, and the temperature and condition of the air outside of the

FIG. 2.—DOUBLE DISCHARGE FAN.
(Niagara Radiator Co.)

chimney, while in the case of a mechanical draft apparatus it depends only upon the power of the motor to run the fan; if a high draft is desired it is run faster and if a low draft is desired it is slowed down. Unless the chimney be built very high the draft produced by it cannot be very great and the range of draft therefore cannot be great; further, the draft can only obtain its maximum when the fire in the furnace is hot, so as to make the gases in the chimney have a high temperature. In the case of a mechanical draft apparatus the draft can be increased by speeding up the fan, without regard to the condition of the fire in the furnace. In the case of a chimney the draft can be increased only as the increase in the combustion takes place, and this combustion is due to the draft. The two are dependent on one another in such a way that it is quite impossible to increase either suddenly. While in the case of the mechanical draft it is possible to suddenly increase the draft irrespective of the condition of either the fire or the draft previously, and this increase in draft is at once followed by an increase in the combustion in the furnace. Again, the temperature of the air outside may have a material affect on the draft of a chimney, while it cannot affect at all the draft of a me-

chanical draft apparatus. And further, the higher draft that can be created by means of the mechanical draft apparatus enables a poorer grade of coal to be used than could be burned with the chimney draft, and this usually results in a marked reduction in the running expense. In the case of a high draft the rate of combustion is higher than in the case of a low, and this results in a hotter fire and therefore for some fuels a more perfect combustion of the fuel in the furnace. It has also been found that less air is required for the complete combustion of a pound of coal when the draft is high than when it is low, and this means, therefore, an economy for the higher draft, because of the smaller amount of heat carried away by the hot gases.

Future Increase of Plant. In regard to the provision for future increase of the power plant there is no question but that the mechanical draft plant has all the advantage. When a chimney is built it must be built very much larger than needed in order to allow for future growth, and this means always a greater first cost than necessary; and when the plant has grown so that the chimney has reached its limit of capacity it then becomes necessary to build a new chimney.

It is because of this continual growth, the rate of which cannot be foreseen, that many plants are equipped with several cheap steel chimneys, each added as the increase of the plants necessitates it, rather than one large brick chimney. In the case of a mechanical draft apparatus the capacity of the plant can be very much increased simply by speeding up the fan, and when this has been done as much as is advisable or economical, it is cheaper to make an addition to the mechanical draft apparatus than it would be to put up a chimney capable of giving the same draft and handling the products of combustion from the same quantity of coal.

High Draft. The advantages of mechanical draft are all due to the high draft which always accompanies it, and to the ability to make the draft suit the requirements of the plant without regard to the temperature of the hot gases or that of the outside air. In most cases it will be found that it is possible to attain the high draft and the attending advantages for a less expenditure of money per year, including interest on first cost and depreciation and repairs of the draft producing apparatus, by means of a properly designed mechanical draft apparatus than by

means of a chimney. And, further, by making the fans and motors in duplicate the danger of a shutdown of the power plant because of some derangement of a fan or its motor may be entirely eliminated.

Mechanical Draft and Economizers. It will be noticed that in what has been said no mention has been made of an economizer to be used in conjunction with the boiler plant. This course has been taken because an economizer can be used with a chimney just as well as with a mechanical draft apparatus, provided always the chimney is of such a height that it will give the required draft when the economizer is used. There are any number of power plants that have economizers where the draft is created by a tall chimney, and the economizers do their work well and are a source of economy. An economizer by cooling the gases before they enter the chimney, reduces the average temperature of the hot gases while in the chimney and thereby brings about a reduction of the draft that would otherwise be created by a chimney of a given height, and necessitates a higher chimney to create a given draft than would be necessary if there were no economizer. The economizer should not be

looked upon as a necessary adjunct to mechanical draft, and the cost of it should not be included as a part of the cost of the mechanical draft apparatus, for while the economizer is almost always a useful and economical adjunct to a power plant its usefulness and economy do not depend upon how the necessary draft is obtained. An economizer working with the hot gases entering it at 550 degrees and the feed water entering at 120 degrees will bring about a certain reduction of the temperature of the gases and a certain increase of the temperature of the feed water, but both of these changes in temperature will be entirely independent of the method adopted for creating the draft which makes the gases pass through the economizer. And while an economizer is a good thing it is no more necessary with a mechanical draft plant than it is with a chimney.

CHAPTER II.

FORCED DRAFT.

Systems. There are two systems of installing a forced draft apparatus. The first consists in making the boiler-room or the fire-room air-tight and creating therein by means of a blower or fan a pressure of air greater than that of the atmosphere; the second consists in making the ash-pit air-tight and creating therein a pressure of air greater than that of the atmosphere. The first system is known as the closed boiler-room or closed fire-room system; and the second is known as the closed ash-pit system. The first system is used principally on ship-board because the air supplied to the furnace for the combustion of the coal serves at the same time to ventilate and aid in keeping cool the fire-room in which the firemen are obliged to work. It is not used on land because of the difficulty and expense of making and keeping the boiler-room or the fire-room air-tight. The second system is used almost entirely on land when a forced draft is used at all, al-

though it has several disadvantages as compared to the first system.

Closed Fire-Room System. With the first or closed fire-room system the pressure of the air on the outside of the ash-pit and the furnace is greater than on the inside, and, therefore, there is a leakage of air into the furnace and ash-pit instead of a leakage of hot gases out into the boiler-room, as there is when the second system is used. Again, there is no blowing out of hot gases or cinders into the boiler-room when the door is opened to put in a fresh charge of fuel with this system as there is apt to be with the closed ash-pit system, unless the pressure maintained in the ash-pit is no more than just sufficient to overcome the resistance to the flow of the air through the bed of fuel on the grate. Further, because the leakage in the case of this system is inward instead of outward as in the other, the boiler setting is not made so hot, and, therefore, does not deteriorate so rapidly when the first system is used as when the second system is used. This last advantage of this system over the closed ash-pit system does not apply to the case of internally fired boilers, but only to externally fired boilers with brick settings.

Closed Ash-Pit System. In order to avoid the objectionable features of forced draft as used on land with a pressure in the ash-pit and not in the boiler-room, it is usual to create in the ash-pit a pressure sufficient to overcome only the resistance to the passage of the air through the fire on the grate, and no more. That is, the pressure in the ash-pit is slightly greater than that of the atmosphere, while in the furnace it is equal to or slightly less than that of the atmosphere. The result is that a chimney must be provided of a height sufficient to create a draft to make the gases flow from the furnace through the flues and passages into the chimney and then out into the atmosphere. As the resistance to the flow of the gases through the fire is about one-half the total draft required when there is no economizer, the draft which must be created by the fan or blower is about one-half the total draft which would be necessary for the complete combustion of the fuel. And since the draft produced by a chimney is directly proportional to its height, it follows that where a forced draft apparatus is used to produce a pressure in the ash-pit sufficient to overcome only the resistance to the flow of the air through the fuel on the grate, there must be a chimney whose height is about one-half the height

of the chimney which would be required for the combustion of the same quantity of fuel without any forced draft apparatus. Or to put it in another way, by the addition of a forced draft apparatus for producing a pressure in the ash-pit, the draft of a power plant can be doubled without any trouble.

When the pressure produced in the ash-pit is greater than that necessary to overcome the friction of the air through the fuel on the grate, there is a pressure in the furnace; and it then becomes necessary to shut off entirely or at least reduce the pressure produced by the apparatus, when the fireman desires to open the furnace door to fire or tend the furnace. If this is not done hot gases and even cinders are blown out into the boiler-room, to the great discomfort of the firemen. For the same reason it is always necessary to shut off the draft before opening the ash-pit door to clean out the ash-pit.

The closed ash-pit system of applying mechanical draft is absolutely necessary with certain forms of furnaces and mechanical stokers which are so constructed as to make the friction of the air through the fuel very great.

Small Fan Required. Because the air handled

by a forced draft apparatus is at a low temperature, never exceeding the temperature of the boiler-room, the volume of air is not so great as it would be if handled at the temperature of the gases in the chimney or the temperature of the gases handled by an induced mechanical draft fan. This means, of course, that the fan required for a forced draft apparatus may be smaller than would be required for an induced draft apparatus for the combustion of the same quantity of fuel; and it also means that since the air handled by the fan is comparatively cool, the bearings are easier to keep cool, and no water is required for cooling them, as is always required in the case of an induced draft apparatus.

Usual Pressure. It is a curious thing that while a forced draft apparatus by which a pressure is maintained in the ash-pit just sufficient to overcome the resistance to the passage of the air through the grate, need not be capable of maintaining a pressure in the ash-pit of much if any more than 0.6 of the total draft required for the combustion of the fuel, the fan used is almost always put in to handle the air at, and capable of creating in the ash-pit, a much higher draft than required, higher even than an induced me-

FIG. 3.—INDUCED DRAFT APPARATUS, WASHINGTON UNIVERSITY, ST. LOUIS, MO.

chanical draft would be designed for, and the proper pressure in the ash-pit is secured by throttling the pressure created by the fan. This is done in order to reduce the first cost of the apparatus, so that the total cost of the fan and its motor, together with the cost of the chimney which must be used in connection with it may be kept as low as possible. This procedure, while reducing the first cost of the mechanical draft apparatus, increases the cost of operation, as it requires more power to run the fan so as to give the higher pressure than would be required to run it to give the lower pressure which is necessary. The fans are usually chosen of such a size that they must be run at a speed sufficient to give a pressure of 1½ or 2 inches of water in order to handle the volume of air required for the combustion of the fuel.

Thus, suppose a certain plant is to be designed to burn 5,000 pounds of coal per hour with a draft of one inch. A forced draft apparatus would consist of a fan capable of giving a pressure in the ash-pit of about 0.6 of an inch and a chimney at least 80 feet high. A fan running at a speed to give only the required pressure of 0.6 of an inch would require a wheel 6½ feet in diameter to handle the air required, while a

fan running at a speed to give a pressure of about 1.5 inches while handling the required amount of air would have a wheel only 5 feet in diameter. It is probable that the smaller wheel would be used, although the power required to run it would be 2½ times what would be required to run the larger fan, and the pressure in the ash-pit would be regulated by throttling the air at the point of delivery into the ash-pit.

Forced Draft and Economizers. When an economizer is used with the closed ash-pit system of forced draft, the chimney must be of sufficient height to overcome the friction of the gases through the economizer as well as through the flues of the boiler and through the chimney itself, as the pressure due to the fan is not supposed to extend beyond the furnace.

Advantages. The advantages claimed for the closed ash-pit system of forced draft are:

1 — Small volume of air to be handled. This is due to the low temperature at which the air is handled.

2 — Small first cost of mechanical apparatus. The cost meant here does not include the cost of the chimney, which is absolutely necessary in

conjunction with this system of mechanical draft. And, further, the cost of the mechanical apparatus is usually reduced by putting in a small apparatus and increasing the running expense.

3 — No danger of overheating of the bearings, and no water required for cooling them. This is due to the low temperature of the air handled by the apparatus.

Disadvantages. The disadvantages of the closed ash-pit system are:

1 — The necessity of a chimney of a height to give a draft sufficient to overcome all the resistances to the flow of the gases through the different flues and out of the chimney; that is, all the draft except what is necessary to overcome the resistance due to the fuel on the grate.

2 — Less flexibility and less control of draft. This is due to the fact that part of the draft, about 40 or 50 per cent, is natural or chimney draft, the remainder only being mechanical draft.

3 — Not adapted for use with economizers. This is not a valid objection if the chimney be made high enough to give a draft sufficient to overcome the resistance due to the economizer as well as that due to the friction of the gases in their passage from the furnace to the top of the

chimney. If the chimney is not high enough to give this required draft the objection is valid, as the pressure due to the fan is not supposed to be more than sufficient to overcome the friction of the air through the fire on the grate.

4 — Leakage of air outward into the boiler-room. With a good ash-pit this leakage is not great, and the objection cannot amount to much so long as the pressure is not so great as to make a pressure in the furnace. If the pressure is so great as to make a pressure in the furnace then there is a leakage of hot gases outward, which is bad for the firemen and causes an overheating of the boiler setting. The main objection to the outward leakage is that it requires that the draft shall be shut off when the ash-pit doors are opened to clean the ash-pit, as if this is not done ashes will be blown into the boiler-room.

5 — Difficulty of controlling the fire. Because of the fact that the ash-pit doors must be kept closed it is more difficult to keep watch of the fire when the closed ash-pit system of mechanical draft is used than when chimney or induced mechanical draft is used. And unless the air is admitted so as to be uniformly distributed over the underside of the grate, the combustion is likely to be very much more rapid in certain

places than in others, so that there is a tendency for the fire to burn out in spots. When this happens the air rushes through these spots into the furnace, and by impinging on certain parts of the boiler, because of its temperature being lower than that of the products of combustion, causes a partial cooling of these parts, and therefore, causes an unequal expansion in the parts of the boiler which is likely to result in trouble of some kind or other. This is much more likely to occur with a high pressure than a low pressure. In fact, when the outlet for the air into the ash-pit is properly designed and located, and the pressure maintained in the ash-pit is not greater than that necessary to overcome the resistance due to the fire on the grate, there is little trouble from burning through of the fire in spots, and this disadvantage is not often apparent in the case of the closed ash-pit system as applied to boilers on land.

CHAPTER III.

INDUCED DRAFT.

Introduction. The fan used in an induced draft system is placed beyond the boiler in the uptake and by its action a partial vacuum is maintained in the uptake, the flues and other passages for the gases, and in the furnace. The air enters the furnace because the pressure there is less than that of the atmosphere. The gases of combustion flow from the furnace to the fan, and then are discharged into the atmosphere through a chimney which need be no higher than absolutely necessary to make the gases clear the neighboring buildings, so that usually the chimney is short and it may be of comparatively cheap construction.

As all the draft is due to the action of the fan, it is under perfect control and may be increased or decreased at will by speeding up or slowing down the fan. The draft produced is of exactly the same kind as that produced by a chimney; and since the pressure inside of the boiler setting

and furnace is less than that of the atmosphere the leakage is from without in, so that there is no escape of hot gas into the boiler-room, nor any blowing out of ashes or cinders into the boiler-room when the furnace or ash-pit doors are opened. Further, there is no tendency to make the walls of the boiler setting hotter by forcing hot air into them. Neither is there the same tendency for the fire to burn through in spots that there is with the closed ash-pit system of forced draft, because there is no jet of air impinging on any one spot of the fire with more force than on others. The flow of air from the ash-pit into the furnace is uniform and regular over all parts of the grate which are covered to the same thickness with fuel.

The fan may be speeded up or slowed down automatically to increase or decrease the combustion in order to preserve a uniform pressure in the boiler, or it may be run at a speed sufficient to give the maximum draft required and then the draft necessary may be obtained by changing the opening of a damper placed in the uptake between the fan and the boiler, in the same manner in which the draft is regulated when produced by a chimney. Since the capacity of a fan, that is to say, the number of cubic feet of gas

that it can handle per minute, varies with the speed at which it is run, the amount of coal burned per minute can be increased by simply increasing the speed of the fan. And as the capacity of the plant to create steam varies almost directly as the amount of coal burned per hour, it is a very easy matter to increase the capacity of the plant as it at most means putting in a larger engine to do the work necessary to run the fan faster.

Temperature of the Gases. Inasmuch as the fan of an induced mechanical draft apparatus handles the hot gases instead of the cool air for combustion, the fan acquires a temperature almost equal to that of the gases, and as this temperature may be as high as 600 degrees or even higher it is necessary to use water cooled bearings for it. Further, as the volume of the gases increases with the temperature, the higher the temperature the greater is the volume of gases which the fan must handle; and for a fan with a wheel of a given diameter this means a higher speed of rotation and more power to drive the fan. The volume of the gases resulting from the combustion of a given quantity of coal when heated to a temperature of about 550 degrees,

quite a common temperature for chimney gases, is about twice as great as the volume of the air supplied to the furnace when at a temperature of about 80 degrees. Whatever, then, reduces the temperature of the gases before they enter the fan, reduces the volume per pound of the gases and therefore increases the weight of gases which the fan can handle when running at a given speed, because the capacity of a fan like that of a pump depends upon its volumetric displacement per unit of time. The greater the weight of gases handled per minute the greater is the weight of coal burned per hour and hence the greater the capacity of the boiler plant as a steam producer. In other words, cooling the gases before they reach the fan not only increases the draft for a given speed of the fan, but also increases the amount of coal which may be burned per hour and hence increases the capacity of the plant as a steam producer, and does not materially change the power required to run the fan. And if the gases can be cooled by increasing the heating surface of the boilers or by the use of an economizer or an air heater, the heat taken from the gases during the cooling process is saved and the steam generated by the plant is obtained more economically.

With a chimney the case is very different, since a reduction in the temperature of the gases entering the chimney means a reduction in the draft as well as a reduction in the volume of gases flowing out of the chimney. If the reduction in the temperature be great, the draft may not be great enough to overcome the friction of the air through the fire and the friction of the hot gases through the various flues and the chimney. The result is that because of the reduction of the draft and in spite of the less volume of gases to be handled by the chimney, the amount of coal that can be burned in the furnace may be, and is very likely to be unless the draft in the first place was greater than necessary, less after the gases are cooled than before. This means, of course, a decrease in the capacity of the whole plant as a steam producer, and may necessitate an increase in the whole plant in order that it may generate the required amount of steam per hour. And the interest on the first cost and the depreciation and repairs on the addition to the plant may more than offset the saving made by cooling the gases. Of course, when the chimney is high enough to give the required draft with the lower temperature of the gases, cooling them brings about a saving in the operation of the

FIG. 4.—INDUCED DRAFT APPARATUS, VICTORIA HOTEL, NEW YORK.
(American Blower Co.)

plant by reducing the quantity of coal necessary to be burned in order to evaporate the required amount of water.

Advantages. The advantages claimed for the induced system of mechanical draft are:

1 — Low first cost. For isolated plants where the nearness to neighboring buildings does not make it necessary to erect a tall chimney in order to discharge the gases at a great height above the ground, the cost of an induced draft system will always be less than the cost of a substantial chimney unless the plant be small. And usually, the cost will be less than the cost of the mechanical equipment and chimney necessary for a system of closed ash-pit, forced draft.

2 — No necessity for a chimney. An induced draft plant never needs a chimney to aid in producing the draft, and whenever a chimney is used with one it is made necessary by other considerations than the draft. When anything more than a short stack is required, the cost of the additional chimney should not be charged as a disadvantage against the mechanical draft plant although it must, of course, be included in the total cost of the draft producing apparatus and may often make the decision of how to produce

the required draft adverse to the induced system.

3 — Control of draft. Since the draft is due entirely to the action of the fan and increases and decreases as the fan is run faster or slower, it is evident that it is entirely under control and can be varied at will to suit the requirements of the instant. With a chimney a hot fire means a high temperature of the escaping gases and therefore a high draft, and a low fire means a low draft; while with an induced draft system the draft may be made low with a hot fire or high with a low fire, and is always independent of everything except the speed of the fan.

4 — Uniform combustion. The combustion in a furnace equipped with an induced system of mechanical draft is just as uniform over the whole surface of the grate as it is with ordinary chimney draft. There is no burning through of the fire in spots as there is likely to be with the closed ash-pit system of forced draft, especially with high drafts.

5 — Leakage inward. This makes it easier for the fireman to tend to the furnace and ash-pit, avoids the trouble due to blowing hot gases or air, or cinders or ashes into the fire-room, even when the furnace or ash-pit doors are open; and further, there is not the same tendency to increase

the deterioration of the boiler or its setting that there is with the closed ash-pit system of forced draft. The leakage is exactly the same as with ordinary chimney draft and produces no more bad effects for the same intensity of draft.

6 — Adaptability to use with economizers. This is one of the strong points in favor of the induced draft system, as cooling the gases after they leave the boiler results in an increase in the number of pounds of water evaporated per pound of coal, and, therefore, an economy in the operation of the boiler plant without affecting the draft. It is possible to do any one of three things when an economizer is used in connection with an induced draft system.

(a) Reduce the speed of the fan until it gives only the draft necessary to burn the required amount of coal. This results in using less steam to run the fan and this saving in steam, together with the saving due entirely to the economizer, will usually result in a marked economy in the operation of the plant.

(b) Run the fan at the same speed and burn a larger quantity of coal of a cheaper grade, so as to evaporate the same amount of water per hour with the economizer that was evaporated before. This almost invariably results in a

marked reduction in the coal bill, and, therefore, since other things remain the same, in an economy in the operation of the plant.

(c) Run the fan at the same speed but burn a larger quantity of the same coal than was used before the introduction of the economizer. This results in an increase in the coal bill, with an increase in the steam capacity of the plant while keeping the fixed charges, such as wages and cost of operation of the fan, the same. The increase in the capacity is always greater than the increase in the coal bill; and since the fixed charges against the plant are increased only by the interest on the first cost, depreciation, repairs and operating expenses of the economizers, the cost of making a pound of steam is materially reduced.

Disadvantages. The disadvantages urged against the use of the induced system of mechanical draft are:

1 — High temperature at which the fans must operate. This resolves itself into simply a question of fact whether the fans can be successfully operated at the high temperature usually found in chimneys either with or without economizers, and experience has proved beyond a shadow of

a doubt that it is perfectly feasible to operate fans even when the gases enter them at a temperature as high as 600 degrees, the temperature of melting lead. This, however, is one of the objections to the use of induced draft systems on war vessels, where at times the rate of combustion may be such that the temperature of the escaping gases may be nearer 1,000 than 600 degrees.

2 — Expense of operating. The operating expenses of induced draft systems when the gases leave at the same temperature at which they should leave a chimney, are greater than the operating expenses of a chimney by the cost of attendance, steam used for running the fan, oil used for lubrication, and water used for cooling the bearings; and in such a case if the cost of operating is not more than offset by interest on first cost, depreciation and repairs, and economy in the operation of the plant as a whole, it is evident that the chimney is the better method of producing the required draft.

3 — Water required to cool the bearings. Ordinarily there is no trouble to get the small amount of water required to cool the bearings of the fan, although if this water be wasted it adds to the cost of operating the apparatus.

When water under pressure is available the cost is simply that of the water, but when the water must be pumped by means of some form of circulating pump to make it circulate from the source of supply through the bearings to be cooled, the cost of running the circulating pump must be added to the cost of the water itself if there be any.

CHAPTER IV.

FUEL AND AIR.

Weight of Coal to be Burned. Since the object of a draft is to supply air for the combustion of a quantity of coal per hour, the first thing to be done in designing an apparatus for producing the draft of a power plant is to determine the weight of coal which must be burned per hour under the given conditions. The weight of coal required to be burned per hour depends upon the weight of water which must be evaporated per hour from and at 212 degrees, and the number of pounds of water, from and at 212 degrees, that can be evaporated per pound of coal burned, and is always equal to the first of these two quantities divided by the second. That is, if W be the weight of water from and at 212 degrees to be evaporated per hour, and w be the weight of water from and at 212 degrees which can be evaporated per pound of coal, the weight of coal, C, which it is necessary to burn per hour is

$$(1) \qquad C = \frac{W}{w}$$

W depends upon the size and type of the engines used; the conditions under which they are used, condensing or non-condensing; the steam used by feed pumps and other auxiliary apparatus; and the steam used for heating or other purposes. It must be determined for each plant, as each becomes a distinct and separate problem because of its own peculiar conditions of working.

Evaporation per Pound of Coal. The number of pounds, w, of water, from and at 212 degrees, that can be evaporated per pound of coal depends upon the heating power of the coal used; the completeness of combustion in the furnace; the rate of evaporation per square foot of heating surface of the boiler; and the type of boiler or kind of heating surface. While there are, of course, other things which may affect the value of w, those mentioned are the main ones. For most boiler plants there is little or no trouble in having the combustion practically complete, provided a sufficient quantity of air is admitted to the furnace.

For boilers of the return fire tube type with good brick settings, the maximum number of pounds of water is found to be evaporated per pound of coal when the rate of evaporation per

square foot of heating surface is about 2.8 pounds of water, from and at 212 degrees, per hour; and for boilers of the water tube type the maximum evaporation per pound of coal is reached when the rate of evaporation per square foot of heating surface is about 3.3 pounds of water, from and at 212 degrees, per hour. That is to say, the maximum value of *w* is reached when the rate of evaporation per square foot of heating surface per hour, in pounds of water from and at 212 degrees, is about 2.8 pounds for fire tube boilers, and 3.3 for water tube boilers.

A study of the tests of boilers made under different conditions seems to indicate that for ordinary draft and hand firing without an economizer, the maximum value of *w* varies for different coals in such a way that if *H* is the heating power of the coal, the probable maximum value of *w* is

$$(2) \qquad w = \frac{H}{1000} - 3$$

Table I shows the probable maximum values of *w* as calculated by equation (2) for coals having different values of *H*.

Effect of Rate of Evaporation. How much *w* may fall below the probable maximum value

as given by Table I will depend principally upon the rate of evaporation per hour per square foot of heating surface of the boiler, and must be ob-

TABLE I.

Maximum Evaporation for Different Coals.

Heating power of coal. *H*	Probable maximum evaporation per lb. of coal. *w*
9000	6
10000	7
11000	8
12000	9
13000	10
14000	11

tained for each particular case. As a guide the following formula, in which e is the rate of evaporation per hour per square foot of heating surface in pounds of water from and at 212 degrees, may be used:

$$(3) \qquad w = z - \frac{e}{2}$$

z depends upon the heating power, H, of the coal and upon the type of boiler or the kind of

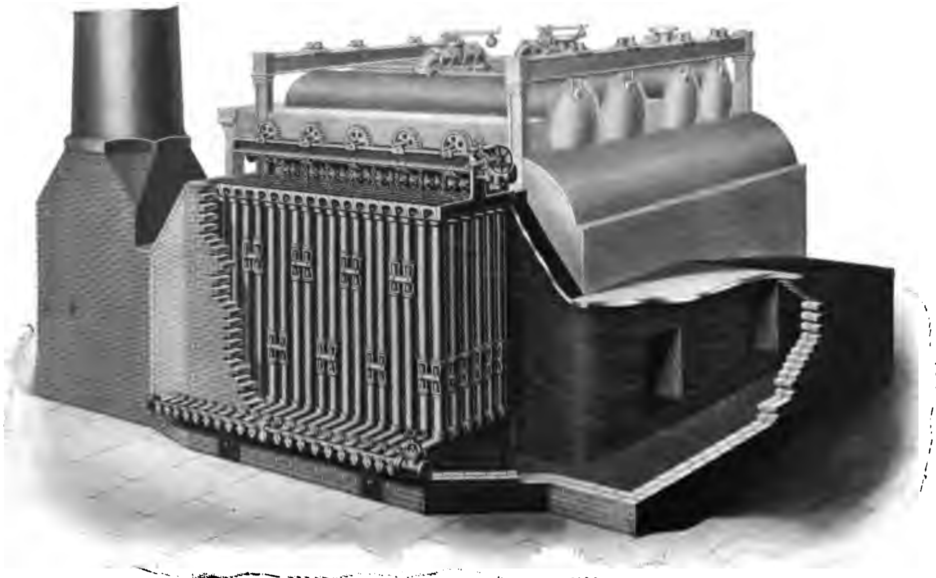

Fig. 5.—Economizer as Applied to Power Plants.
(Green Fuel Economizer Co.)

heating surface, and its value is given in Table II.

TABLE II.

Values of z.

Heating power of coal. H	Kind of boiler.	
	Return fire tube.	Water tube.
9000	7.4	7.7
10000	8.4	8.7
11000	9.4	9.7
12000	10.4	10.7
13000	11.4	11.7
14000	12.4	12.7

It must, of course, be remembered that no single formula can be given which will give exact results for all conditions such as poor, leaky settings, bad firing, insufficient air supply, and the thousand and one other conditions which may decrease the evaporating power of a coal if they be allowed to exist, but which should not exist in a properly designed and cared for boiler plant. And it must further be remembered that economizers and other heat-saving devices will effect an increase in the evaporation per pound of coal

by an amount which can be predicted fairly well only when the circumstances and conditions under which the heat-saving devices are to be used are known.

Weight of Air Required. It may be assumed without any material error that 12 pounds of air are required to supply the amount of oxygen theoretically necessary for the complete combustion of one pound of coal. This would be more nearly true if the coal consisted of pure carbon and contained no hydrogen or no incombustible matter. As, however, it is practically impossible to be sure that in the furnace each particular atom of combustible will be brought in direct contact with the required oxygen if there be only the amount that is theoretically necessary, it is necessary to introduce more air than is theoretically necessary for the complete combustion of the coal. And the results of tests during which the per cents of free oxygen and carbon dioxide in the gases of combustion have been determined, show that combustion is almost always complete when the per cent of oxygen is 6 or 7 and the per cent of carbon dioxide is 14 or 13, indicating about 50 per cent more air than is theoretically necessary. It may be assumed therefore that 18

pounds of air must be supplied to the furnace for each pound of coal burned.

Volume of Air and Gases. The volume of one pound of air measured at 32 degrees is about $12\frac{1}{2}$ cubic feet, and hence the volume of air measured at 32 degrees which must be admitted to the furnace for each pound of coal burned is $18 \times 12\frac{1}{2}$, or 225 cubic feet. If measured at a temperature *t*, the volume would be $\frac{(461+t)225}{493}$, and this multiplied by the weight of coal burned per hour and divided by 60 will be the cubic feet of air which the draft producing apparatus must handle per minute.

The volume of the gases resulting from the combustion in the furnace may for all practical purposes be considered as equal to the volume of the air supplied for combustion, when both are measured at the same temperature. Hence the volume of the air or the gases to be handled per minute by the draft producing fans is

$$(4) \qquad A = \frac{225C(t + 461)}{493 \times 60} = \frac{C(t + 461)}{131}$$

A is the volume in cubic feet of air or gases to be handled per minute; *C*, the weight of coal to be burned per hour; and *t*, the temperature at which the air or gases are handled by the draft producing fan.

The value of the volume factor $\frac{t+461}{131}$, for different values of *t* at which the fan of a mechanical draft apparatus must handle the air or gases of combustion are given in Table III.

TABLE III.

Value of Volume Factor.

Temp. of the air or gases. t	$\frac{t+461}{131}$
60	4.0
80	4.1
100	4.3
200	5.0
300	5.8
400	6.6
500	7.3
600	8.1

Volume of Gases to be Handled. The fan of a forced draft apparatus handles the air required for combustion at probably some tem-

perature in the neighborhood of 60 degrees; and as Table III shows that the value of $\frac{t+461}{131}$ for 60 degrees is 4, we have from equation (4): *the number of cubic feet of air to be supplied per minute by the fan of a forced draft apparatus is equal to four times the number of pounds of coal burned per hour.*

The fan of an induced draft apparatus *with* an economizer handles the gases of combustion at a temperature usually between 250 and 350 degrees, so that we may say from Table III and equation (4): *the number of cubic feet of gases to be handled per minute by the fan of an induced draft apparatus with an economizer is equal to six times the number of pounds of coal burned per hour.*

The fan of an induced draft apparatus *without* an economizer is not likely to be called upon to handle the gases at a temperature exceeding 600 degrees and hence we may say: *the number of cubic feet of gases to be handled per minute by the fan of an induced draft apparatus without an economizer is equal to eight times the number of pounds of coal to be burned per hour.*

If we put in (4) the probable values of t for the various conditions under which the fan of a

mechanical draft apparatus must handle the air or gases of combustion we get

$$(5) \qquad \left.\begin{array}{l} 4C, \text{ for forced draft;} \\ 6C, \text{ for induced draft with an} \\ \qquad \text{economizer;} \\ 8C, \text{ for induced draft without} \\ \qquad \text{an economizer.} \end{array}\right\} = A$$

Leakage increases the volume of air or gases of combustion the fan must handle. In the case of forced draft of the closed ash-pit system all the air which passes through the fan does not enter the furnace because of the leakage outward from the ash-pit through the walls of the setting and through the cracks of the ash-pit doors. And in the case of an induced draft system the fan must handle all of the air which leaks into the furnace or flues and mingles with the products of combustion. The leakage is in all cases greater for a high draft or pressure than for a low one. By exercising care in the erection of a boiler plant the leakage may be made quite insignificant, although there are many plants in which the leakage probably amounts to fully 15 or 20 per cent of the total volume of the gases passing out of the chimney.

A factor of safety should of course be used in this work as in all engineering work and it is well to introduce it when determining the value of C, as all the calculations are based upon the number of pounds of coal which must be burned per hour.

CHAPTER V.

DRAFT.

Relation to Rate of Combustion. The draft necessary for the combustion of a given amount of coal depends upon the velocity of the escaping gases of combustion, the friction of the air through the fuel into the furnace, and the friction of the gases of combustion through the various passages from the furnace to the top of the chimney. When there is no flow of air into the furnace and no flow of gases out, the draft necessary is zero, because there is no friction when there is no velocity. The pressure or the draft necessary to overcome the friction increases as the square of the velocity of the gases flowing out, and hence as the square of the velocity of the entering air. And since the combustion per square foot of grate surface is directly proportional to the velocity of the entering air, the draft necessary is directly proportional to the square of the number of pounds of coal burned per hour

per square foot of grate surface. Or to put it another way, the number of pounds of coal burned per square foot of grate surface is directly proportional to the square root of the draft.

Let F be the number of pounds of fuel burned per square foot of grate surface per hour; i, the draft in inches of water measured at the end of the uptake just where it enters the chimney; and k, a factor whose value depends upon the kind of fuel and its condition of fineness: then

$$F = k\sqrt{i} \tag{6}$$

and

$$i = \frac{F^2}{k^2} \tag{7}$$

The results of many tests show the rate of combustion per square foot of grate surface for grates of different kinds, for coals of various grades and degrees of fineness, and different drafts, but they seem to have been made under very different conditions and therefore it is difficult to arrive at the value of k for a particular kind of coal under a given set of conditions. Again it will often be found that under apparently exactly the same conditions, when using the

same boiler, furnace, and chimney, and the same coal, a higher rate of combustion will be obtained with a low than with a high draft. Such results are only explainable by the supposition that when the high draft was had, the damper between the chimney and the boiler was partly closed so that the full effect of the draft was not felt in the furnace. This means, of course, that when going over a series of tests made by an observer on a boiler plant with a particular kind of coal, care must be taken to select only the highest rate of combustion for a particular draft, and use that rate to obtain a proper value of k in equations (6) and (7).

Hutton. Hutton in his book, Steam Boiler Designing, gives a table showing the drafts necessary for the efficient combustion of different fuels, but the table conveys very little information and is of practically no aid to an engineer when designing a plant, because it gives no intimation at all as to the number of pounds of each fuel that may be burned per square foot of grate surface per hour with the draft which is stated in the table to be suitable to it. Thus he gives 0.20 inches of water as the draft required for straw, and 1.2 to 1.4 as that required for round

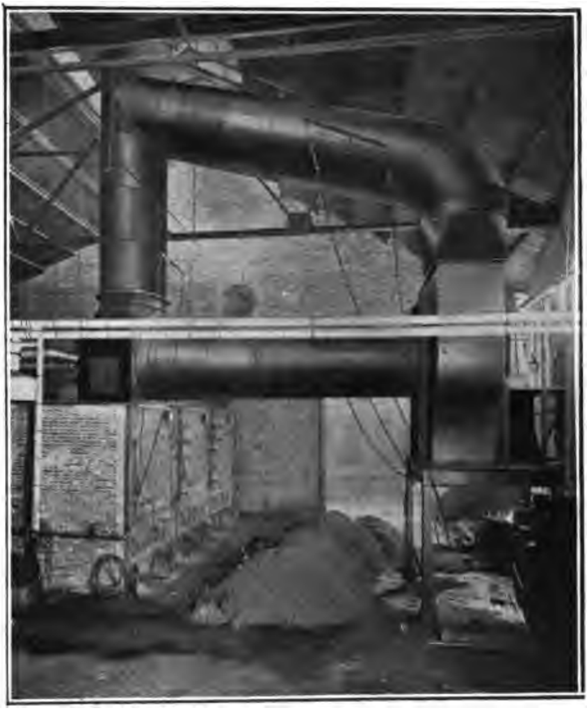

FIG. 6.—INDUCED DRAFT APPARATUS, NEPTUNE CONSUMERS' ICE CO., BROOKLYN, N. Y. (American Blower Co.)

anthracite. But whether it is possible to burn 10 pounds of straw and 20 pounds of anthracite per hour per square foot of grate surface, or *vice versa*, there is no way of telling from any explanation given with the table. Hutton also gives a table showing the draft obtained with chimneys of different heights, and the number of pounds of coal that may be burned per hour per square foot of grate surface with the given drafts. The drafts are calculated on the supposition that the draft in inches of water is equal to 0.00729 times the height of the chimney in feet. If k be calculated from the table it is found that its value varies from about 23 for chimneys 60 and 80 feet high, assumed to give drafts of 0.44 and 0.58 of an inch, to about 55 for a chimney 225 feet high, assumed to give a draft of 1.64 inches.

Thurston in his book, Manual of the Steam Boiler, gives certain formulas showing the relation between the rate of combustion per square foot of grate surface and the height of a chimney. Assuming that the draft in inches of water is ordinarily something between 0.005 and 0.007 times the height of the chimney in feet, the writer finds that modifications of Thurston's formulas give for anthracite under best conditions

$$F = (28 \text{ to } 24)\ \sqrt{I} - I$$

and for anthracite under ordinary conditions

$$F = (21 \text{ to } 18)\ \sqrt{I} - I$$

And for "the best Welsh and Maryland semi anthracite or good bituminous and semi-bituminous coals,"

$$F = (31 \text{ to } 27)\ \sqrt{I} - I$$

For "the less valuable soft coals,"

$$F = (42 \text{ to } 36)\ \sqrt{I} - I$$

Whitham's Tests. Whitham in a paper read before the American Society of Mechanical Engineers in 1896,* gives a table showing the rate of combustion per square foot of grate surface per hour under different conditions when using a good quality of bituminous coal with a return fire tube boiler and hand firing. From this table by Whitham, Table IV has been obtained. The values of *k* given in Table IV have been calculated by the writer from the two other items which have been taken from Whitham's table.

*Trans. A. S. M. E., Vol. XVII, 1896.

Table IV shows a gradually increasing value of k with an increase in the intensity of the draft, which is not what we should expect, and is prob-

TABLE IV.

Whitham's Tests.

Rate of Combustion. F	Draft. i	k
5	0.08	17.7
8	0.16	20.0
10	0.20	22.4
12	0.24	24.5
14	0.29	26.0
15	0.31	26.9
16	0.33	27.8
18	0.36	30.0
20	0.40	31.6
22	0.44	33.2
25	0.49	35.7
28	0.53	38.5
30	0.57	39.7
34	0.63	42.8
36	0.67	44.0
40	0.74	46.5

ably due to less air being admitted to the furnace per pound of coal at the higher drafts than at the lower.

The actual results of the experiments upon which Whitham bases his table are given with the corresponding values of k, as calculated by the writer, in Table V.

TABLE V.

Whitham's Tests.

Rate of combustion. F	Draft i	k
6.49	0.16	16.2
8.89	0.21	19.4
12.13	0.33	21.1
16.35	0.36	27.2
19.20	0.42	29.6
20.87	0.51	29.2
26.55	0.65	33.0
30.10	0.62	38.2
34.30	0.67	41.8

Goss' Tests. In 1901 Goss * in a paper describing some tests made on the locomotive in the laboratory of Perdue University gives the rates of combustion observed for 35 tests for which the draft varied from 1.72 inches to 7.48

* Trans. A. S. M. E., Vol. XXII, 1901.

inches. The lowest draft gave a rate of combustion of coal per hour per square foot of grate surface of 49.3 pounds; and the highest gave a rate of 181.6 pounds. The coal used was Brazil block, and the lowest rate of combustion, 45.9 pounds, was obtained with a draft of 1.93 inches. As a result of his experiments Goss gives a purely imperical formula, of not even rational form, to express the relation between draft and rate of combustion, as follows:

$$i = 0.037\ F$$

Wagner's Tests. Wagner discussing the paper by Goss gives the results of eight tests made on a locomotive to determine the relation between draft and rate of combustion. Four of these tests were shop tests, that is they were made in the shop; and four were road tests, made with the locomotive under actual working conditions. In the shop tests the draft varied from 2.9 to 3.8 inches while the rate of combustion varied from 104.8 to 110.3. For the average rate of combustion and the average draft of the shop tests *k* is about 58.

The results of the road tests together with the

value of k as calculated by the writer are given in Table VI.

TABLE VI.

Wagner's Tests.

Rate of combustion. F	Draft. i	k
23.0	0.92	24.0
52.3	2.80	31.3
56.4	3.23	31.4
99.6	5.15	43.9

Value of k. After a careful study of the results of a large number of boiler trials and as the result of his own experience and experiments the writer is of the opinion that it is safe to give to k the following values for boilers without economizers or air heaters, with ordinary stationary grates having about 50 per cent air space:

$$k = \begin{cases} 34 \text{ for bituminous block;} \\ 28 \text{ for bituminous slack;} \\ 24 \text{ for anthracite nut;} \\ 20 \text{ for anthracite slack.} \end{cases}$$

Resistance of Grate. Writers have variously

estimated the resistance to the flow of the air through the fuel on the grate to be from 0.4 to 0.75 of the total draft necessary for the combustion of the coal at the required rate. The resistance, of course, depends upon the velocity of the entering air, and hence upon the volume of air admitted per pound of coal burned and the rate of combustion. It also depends upon the thickness of the bed of fire and ashes, being less for a thin than for a thick fire. It is greater with a clinkering bituminous than with an anthracite coal; and it may often be very materially reduced by a free use of the slice bar.

Whitham,* in the experiments already referred to, measured the resistance to the flow of air through the fuel on the grate, which was of the stationary type, herring-bone pattern, with air openings equal to 46 per cent of the grate surface, and found that this resistance varied from 0.44 to 0.62 of the total draft, and as an average was about one-half the total draft. The results of Whitham's experiments with the ratio of the grate resistance to the total draft are given in Table VII.

* Trans. A. S. M. E., Vol. XVII, 1896.

TABLE VII.

Resistance of Grate.

Grate resistance.	Total draft.	Grate resistance divided by total draft.
0.7	0.16	0.44
0.13	0.21	0.62
0.17	0.33	0.52
0.19	0.36	0.53
0.24	0.42	0.57
0.25	0.51	0.55
0.36	0.65	0.49
0.30	0.62	0.48
0.32	0.67	0.47
Average,		0.52

It is safe to assume that the draft necessary to overcome the resistance to the flow of the air through the coal of a grate of the ordinary stationary type having about 50 per cent air space, is 0.6 of the total draft required for the combustion of the coal. And hence in the case of a closed ash-pit system of forced draft the fan must be capable of maintaining in the ash-pit a pressure equal to 0.6 of the total draft as determined by equation (7); and at least 0.4 of the

total draft must be produced by a suitable chimney.

Resistance due to Economizer. It is extremely difficult to determine the resistance to the flow of the gases due to the tubes of an economizer, because of the few tests that are get-at-able. It, of course, depends upon the arrangement of the tubes more than anything else. If the tubes be arranged so that the velocity through the economizer is high then the resistance will be greater than if they be arranged so that the velocity is low. The few tests to which the author has had access indicate that the resistance due to the economizer may be even as high as 70 per cent of the total draft, and that ordinarily it is between 30 and 40 per cent of the total draft. That is, if the draft be measured beyond the economizer, on the side near the fan or chimney, and be, say, 0.50 of an inch, we should expect a draft of about 0.3 to 0.35 of an inch between the economizer and the boiler. The draft between the economizer and the boiler is the draft which is available for overcoming the resistance of the air through the grate, and of the hot gases on their way from the furnace to the economizer. And since the resistance of the economizer is

about one-third the total draft measured beyond the economizer, we may say that the draft necessary with an economizer is about 50 per cent greater than that necessary without an economizer. This does not mean that an economizer can never be put into a plant without increasing the height of the chimney, because often the draft given by the chimney is much greater than is necessary.

The effect of an economizer on the draft of an old plant is to make it less by an amount depending entirely upon the decrease of the temperature of the gases in the chimney. If the economizer reduces the temperature of the gases to between 300 and 350 degrees, the reduction of the draft produced by a chimney of a given height will be about 15 per cent, if the original temperature of the gases without the economizer were about 400 degrees, 25 per cent if the original temperature were about 500 degrees, and 35 per cent if the original temperature were about 600 degrees. This means that if a plant has a chimney which without an economizer gives a draft of, say, 0.6 of an inch with a temperature of the gases of about 500 degrees, we should expect the draft between the chimney and the economizer to be only about 0.40 to 0.45 of an inch after the econ-

FIG. 7.—ECONOMIZER, ATLANTA CONSOLIDATED STREET RAILWAY CO., ATLANTA, GA.
(Green Fuel Economizer Co.)

omizer is put in. And we should expect that of this draft of 0.4 or 0.45 of an inch about one-third would be used in overcoming the resistance due to the economizer, leaving a draft of about 0.3 of an inch between the economizer and the boiler. In this particular case, then, the available draft measured near the boiler has been reduced from about 0.6 to about 0.3 of an inch by the introduction of an economizer. And whether or not the use of the economizer will reduce the capacity of the plant depends entirely upon whether the draft available at the boiler is less than that necessary for the combustion of the required amount of coal. If the available draft be less than that necessary, the rate of combustion per hour per square foot of grate surface will be decreased, and the capacity of the plant will be decreased; while if the available draft be greater than that necessary, the capacity of the plant will not be decreased by the use of an economizer, and the cost of running the plant will usually be made less than before the economizer was put in.

Hence, when designing a mechanical draft apparatus, we first determine the draft necessary without an economizer for the rate of combustion desired, and then increase this by 50 per cent to

get the draft necessary for the *same rate* of combustion when an economizer is used. That is, to determine the draft necessary for a given rate of combustion with an economizer, multiply the value of i as given by equation (7) by 1.5.

TABLE VIII.

Induced Draft Necessary without an Economizer.

Rate of Combustion. F	Necessary draft, i, in inches of water.			
	Bituminous Coal.		Anthracite Coal.	
	Block.	Slack.	Nut.	Slack.
5	0.02	0.03	0.04	0.06
10	0.09	0.13	0.17	0.25
15	0.20	0.29	0.39	0.56
20	0.35	0.51	0.70	1.00
25	0.54	0.81	1.08	1.56
30	0.78	1.15	1.56	2.25
35	1.06	1.56	2.12	3.06
40	1.39	2.04	2.78	4.00
45	1.75	2.58	3.52	5.08
50	2.16	3.20	4.34	6.25

Draft Required under Different Conditions. Table VIII gives the draft as calculated by

equation (7) which must be maintained in the up-take of a boiler plant *without* an economizer by the fan of an induced draft apparatus for different coals when burned on an ordinary stationary grate having about 50 per cent air space, at various rates of combustion in pounds per hour per square foot of grate surface.

TABLE IX.

Induced Draft Necessary with an Economizer.

Rate of Combustion. F	Necessary draft, i, in inches of water.			
	Bituminous Coal.		Anthracite Coal.	
	Block.	Slack.	Nut.	Slack.
5	0.03	0.05	0.07	0.09
10	0.13	0.19	0.26	0.38
15	0.29	0.43	0.58	0.84
20	0.52	0.76	1.04	1.50
25	0.81	1.19	1.62	2.34
30	1.17	1.72	2.34	3.37
35	1.59	2.34	3.18	4.59
40	2.08	3.06	4.16	6.00
45	2.62	3.87	5.27	7.60
50	3.25	4.78	6.50	9.36

Table IX gives the draft which must be maintained in the up-take of a boiler *with* an econo-

mizer by the fan of an induced draft apparatus for different coals when burned on an ordinary stationary grate having about 50 per cent air space, at various rates of combustion in pounds per hour per square foot of grate surface. This table is obtained by multiplying the draft given by equation (7) for a given rate of combustion by the factor 1.5.

Table X gives the pressure which must be maintained in the ash-pit of a closed ash-pit system of mechanical draft in order to just overcome the resistance to the friction of the air passing through the fire on an ordinary stationary grate with about 50 per cent air space, when burning different coals at different rates of combustion in pounds per hour per square foot of grate surface. This table is obtained by multiplying the draft given by equation (7) by the factor 0.6.

It must be remembered that when using a closed ash-pit system of forced draft without economizers it is necessary to provide a chimney of sufficient height to give a draft equal to at least 0.4 of the total draft, or two-thirds of the draft given by Table X for a given rate of combustion for a particular kind and quality of coal.

TABLE X.

Forced Draft, Pressure Necessary, Closed Ash-pit System.

Rate of Combustion. F	Necessary pressure i, in inches of water.			
	Bituminous Coal.		Anthracite Coal.	
	Block.	Slack.	Nut.	Slack.
5	0.02	0.02		
10	0.05	0.08	0.03	0.04
15	0.12	0.17	0.10	0.15
20	0.21	0.31	0.23	0.34
25	0.32	0.48	0.42	0.60
30	0.47	0.68	0.65	0.94
35	0.64	0.94	0.94	1.35
40	0.83	1.22	1.28	1.84
45	1.05	1.55	1.67	
50	1.30	1.91		

CHAPTER VI.

ECONOMIZERS.

Effect of Adding. The addition of an economizer to a boiler plant is equivalent to increasing the heating surface of the plant and always results in a decrease in the temperature of the escaping gases and an increase in the temperature of the feed water, and it is the heat given to the feed water to which the economy in the use of the economizer is due. The economy is two fold: first, more heat is taken from the products of combustion; and, second, because of the higher temperature at which the feed water enters the boiler, the evaporation in pounds of water from and at 212 degrees per hour per square foot of heating surface is reduced, thus bringing about an increase in the efficiency of the boiler, or the weight of water evaporated from and at 212 degrees per pound of coal. And hence the saving in coal due to the use of an economizer is usually greater than the saving in

heat actually required for the evaporation of the water under the two conditions.

To make this more apparent let it be supposed that an economizer is to be put in a plant which is required to evaporate 30,000 pounds of water per hour from an initial temperature of 120 degrees and under a boiler pressure of 100 pounds. This is equivalent to 33,200 pounds of water per hour from and at 212 degrees. Let it also be supposed that the coal used has a heating power of 13,000 heat units, and that the boilers are of the water tube type working at the rate of 4 pounds of water from and at 212 degrees per hour per square foot of heating surface. From equation (3) we have that the weight of water evaporated from and at 212 degres per pound of coal is

$$w = z - \frac{e}{2}$$

$$= z - \frac{4}{2} = z - 2$$

From Table II we find that z for a coal having a heating power of 13,000 heat units used with a water tube boiler, is 11.7. Hence,

$$w = 11.7 - 2 = 9.7$$

Therefore, the coal required per hour without the economizer is

$$C = \frac{33200}{9.7} = 3420$$

If an economizer of proper size be put in it would probably be safe to say that the water would enter the boiler at 225 degrees instead of 120. That is, the temperature of the feed water would be raised from 120 to 225 degrees during its passage through the economizer. Then the boiler would evaporate 30,000 pounds of water per hour from an initial temperature of 225 degrees, under a boiler pressure of 100 pounds, which would be equivalent to evaporating 29,800 pounds of water per hour from and at 212 degrees. The rate of evaporation then in pounds of water from and at 212 degrees per square foot of boiler heating surface would be not 4, but

$$\frac{29800 \times 4}{33200} = 3.6$$

From equation (3) and Table II we find that for a water tube boiler and a coal having a heating power of 13,000, the weight of water evap-

orated from and at 212 degres per pound of coal for a rate of evaporation per square foot of boiler heating surface of 3.6 pounds, is

$$w = 11.7 - \frac{3.6}{2}$$

$$= 11.7 - 1.8 = 9.9$$

And the coal used per hour with the economizer would be

$$C = \frac{29800}{9.9} = 3010$$

The per cent of saving of coal by the use of the economizer would be

$$\frac{100\,(3420 - 3010)}{3420} = 12.0$$

The per cent of saving in heat that must be supplied by the boiler is the same as the per cent of saving of water from and at 212 degrees which the boiler must evaporate; and hence the per cent of saving in heat which the boiler must supply would be

$$\frac{100\,(33200 - 29800)}{33200} = 10.2$$

In this particular instance the per cent of saving of coal due to the economizer is increased by 1.8 simply because of the reduction of the evaporation per hour per square foot of boiler heating surface. In other words, in this particular case, since 1.8 is about 0.15 of 12.0, it is seen that about one-seventh of the total economy due to the use of the economizer is due to the less rate of evaporation per square foot of boiler heating surface.

Instead of being used to reduce the cost of evaporating a given amount of water per hour, an economizer may be used to bring about an increase in the steam producing capacity of a plant without any increase in the cost of fuel. Inasmuch, however, as the cost of an economizer might be much greater than the cost of an additional amount of boiler surface for a given increase in steam producing capacity, economizers are seldom used except to reduce the cost of producing a given amount of steam by utilizing such heat as would otherwise be wasted.

Ordinary Proportion and Cost. Economizers are usually designed and the surface in them proportioned upon one square foot of surface to 6 pounds of water actually evaporated per hour

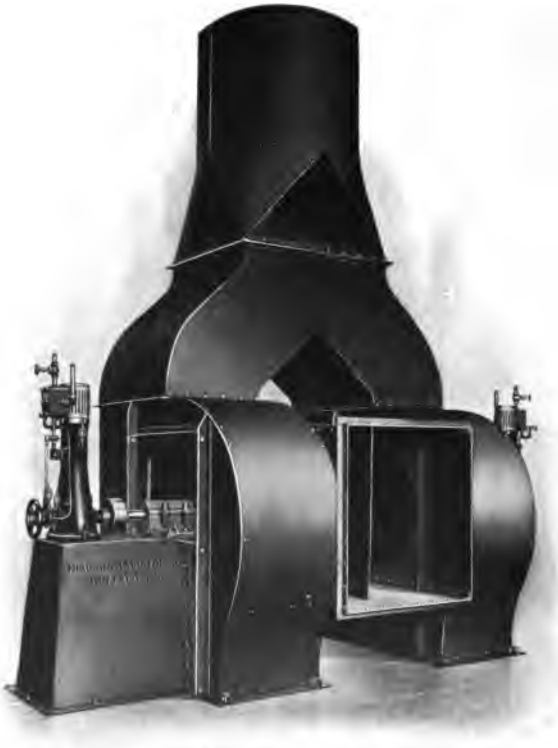

FIG. 8.—INDUCED DRAFT APPARATUS, STATE CENTRAL HEATING PLANT, JEFFERSON CITY, MO.
(Niagara Radiator Co.)

by the plant; sometimes, however, the ratio is as low as one square foot of surface to 7 pounds of water, and other times as high as one square foot to 5 pounds of water. The cost of an economizer is greater than the cost of a boiler of the return fire tube type having the same number of square feet of heating surface, and less than the cost of a boiler of the water tube type with the same number of square feet of heating surface.

Increase of Temperature of Feed Water. It is almost impossible to predict exactly the rise of temperature of the feed water while passing through an economizer, because of the great number of factors involved. It depends upon the initial temperature of the water, the velocity of the water through the pipes; the number of square feet of economizer surface provided per pound of water; the degree of cleanliness of the surface of the economizer, inside and outside: the initial temperature of the hot gases; the weight or volume of the gases coming in contact with the economizer per pound of water passing through it; and, finally, upon the velocity of the gases passing over the surface. The rate of transfer of heat from the gases to the water seems to be somewhere between 2 and 3 units

per hour per degree difference of temperatures of the gases and the water.

Roney, in a paper on Mechanical Draft,* read before the American Society of Mechanical Engineers, gives a table showing the initial and final temperatures of both the water and the gases observed on tests of economizers of nine plants. It is not quite clear whether all of the tests are made on different plants or whether more than one are made on the same plant; and, further, there are no data given as to the ratio of weight of feed water to area of surface of economizer that would enable any general conclusions to be drawn from the tests which would be of much value in designing a boiler plant with economizers in order to get a given final temperature of feed water. Roney's results are given in Table XI.

A study of economizers shows that it is possible to deduce a formula of rational form which will indicate the relation which must exist between the variables involved, but to obtain the different constants that are necessary to enable such a formula to be put in useable condition is very difficult. The writer gives in equation (8) a formula for determining the rise in temperature of the feed water during its passage through

* Trans. A. S. M. E., Vol. XV, 1894.

the economizer, and in equation (9) a formula to determine the fall of temperature of the gases. In these equations, t_1 is the initial temperature of the water; t_2, the final temperature of the water after passing through the economizer; T_1,

TABLE XI.

Roney's Experiments with Economizers.

Temperatures of the gases.		Temperatures of the water.	
Initial.	Final.	Initial.	Final.
610	340	110	287
505	212	84	276
550	205	185	305
522	320	155	300
505	320	190	300
465	250	180	295
490	290	165	280
495	190	155	320
595	299	130	311

the initial temperature of the hot gases; T_2, the final temperature of the gases; B, the number of pounds of water flowing through the economizer per hour per square foot of economizer surface; w, the weight in pounds of the water actually evaporated per pound of coal; and a, the weight in pounds of the gases admitted to the economizer per pound of coal burned.

$$(8) \qquad t_2 - t_1 = \frac{T_1 - t_1}{\frac{B}{2.4} + \frac{w}{0.5a} + 0.5}$$

$$(9) \qquad T_1 - T_2 = \frac{w\,(t_2 - t_1)}{0.25a}$$

It may be assumed without a great deal of error, that *a*, the weight of gases admitted to the economizer per pound of coal burned, is about 20, so that equations (8) and (9) become

$$(10) \qquad t_2 - t_1 = \frac{T_1 - t_1}{0.42\,B + 0.1\,w + 0.5}$$

$$(11) \qquad T_1 - T_2 = 0.2\,w\,(t_2 - t_1)$$

In Table XII is given the value of the expression $0.42\,B + 0.1\,w + 0.5$ for different values of B and w.

Example. Determine the rise in temperature of the water in an economizer which has an initial temperature of 120 degrees, when the hot gases enter at a temperature of 500 degrees, and the economizer is proportioned on the basis of one square foot of surface to 5 pounds of water,

and the coal used is such that about 9 pounds of water are evaporated under actual conditions per pound of coal.

TABLE XII.

Economizer Factors.

w	Values of B.			
	4	5	6	7
6	2.8	3.2	3.6	4.0
7	2.9	3.3	3.7	4.1
8	3.0	3.4	3.8	4.2
9	3.1	3.5	3.9	4.3
10	3.2	3.6	4.0	4.4

Here we have B is 5, and w is 9, and hence we find from Table XII, that the economizer factor or $0.42\ B + 0.1\ w + 0.5$ is equal to 3.5. Therefore,

$$t_2 - t_1 = \frac{T_1 - t_1}{3.5} = \frac{500 - 120}{3.5}$$

$$= 108$$

$$T_1 - T_2 = 0.2\ w\ (t_2 - t_1)$$

$$= 1.8 \times 108 = 194$$

Since t_1 is 120 and $t_2 - t_1$ is 108, we have

$$t_2 = t_1 + 108 = 228$$

And since $T_1 - T_2$ is 194 and T_1 is 500, we have

$$T_2 = T_1 - 194$$
$$= 500 - 194 = 306$$

That is to say, the water entering the economizer at a temperature of 120 degrees leaves at a temperature of 228 degrees, and the gases entering at a temperature of 500 degrees have their temperature reduced by 194 degrees and leave at 306 degrees.

An inspection of Table XII. shows that the smaller B is, that is the smaller is the number of pounds of water passing through the economizer per hour per square foot of surface, and the smaller is w, the number of pounds of water evaporated under actual conditions per pound of coal, the smaller is the expression

$$0.42\ B + 0.1\ w + 0.5$$

and, therefore, the greater is the increase in the temperature of the feed water passing through the economizer. This means, that the larger the economizer for a given plant and the poorer the coal used, the greater is the saving in heat and coal effected by the economizer.

CHAPTER VII.

FANS.

Type and Proportions of Fans Used. Among the different types of fans on the market may be mentioned as the principal ones, the disk fan, either with straight or curved blades, the cone wheel fan, and the centrifugal fan. And of all, the centrifugal type of fan is the only one which is suitable for use with a mechanical draft apparatus. As used for mechanical draft purposes the centrifugal fans are always provided with a casing or housing of steel plate and therefore they are often termed "steel plate" fans.

A centifugal fan * consists of a fan wheel revolving in a housing or casing provided with suitable inlets for the entrance of the air or gases, and a suitable outlet through which the

* For a full description of centrifugal fans the reader is referred to Centrifugal Fans, by J. H. Kinealy.

air or gases are allowed to pass out and away. The air always enters at the center of the wheel and leaves at the periphery so that the inlets are in the sides of the housing and the outlet in the scroll, as the part of the housing surrounding the periphery of the wheel is termed. If the fan has but one inlet it is termed an exhauster; while if it has two inlets, one on each side of the housing, it is termed a blower. With the exception of this difference in the number of inlets there is no difference between an exhauster and a blower. Of course, the details of construction must be arranged to fit the requirements of the one or two inlets. The wheel revolves in the housing and is supported by a shaft which has two bearings. In the case of a blower there is one bearing on each side of the housing in front of the inlet, and the air entering the fan passes over these bearings. In the case of an exhauster both of the bearings are on the same side of the housing, the side opposite to the one in which the inlet is. The wheel of an exhauster is said, therefore, to be overhung, and the air or gas entering the fan does not come in contact with the bearings. This is an important detail of construction when the fan is used with a mechanical draft apparatus, as since the hot

gases do not then come in direct contact with the bearings it is easier to keep them cool. Of course, there is no reason why a fan with a single inlet and an overhung wheel should not be used as a blower; in fact such fans are often used as blowers, especially when the gases handled are likely to have some injurious effect on the working parts of the apparatus.

The bearing next to the wheel of a fan used with an induced draft apparatus must always be water-jacketed so that a continual stream of water may be used to keep it cool. While the hot gases do not come in direct contact with the bearing they do come in contact with that part of the shaft inside of the housing and the part of the shaft in the bearing is heated by conduction from the hot part.

The pressure against which a centrifugal fan can force air or the suction or draft against which it can draw or suck air can never exceed that corresponding to the velocity in feet per minute of the tips of the blades or floats of the tan wheel; and when a fan both sucks and forces air or gases, the sum of the draft necessary to suck the air and the pressure against which it is forced must not exceed the pressure corresponding to the velocity in feet per minute of the

tips of the floats. The pressure which a fan will create in its housing will depend upon the density of the gas it is handling, the greater the density of the gas the greater will be the pressure created for a given velocity of the tips of the floats of the fan.

Fans of the centrifugal type are usually designated according to the number of inlets, the shape of the housing, the position of the outlet, and the direction of the flow of the air leaving the outlet. If there are two inlets, the fan is a double inlet or double admission fan, while if there is only one inlet and the bearings are both on the same side of the housing, the fan is called a single inlet or single admission fan with overhung wheel. If the housing is completely above the foundation the fan is said to be a full housed fan, and if a part, usually about one-quarter, of the housing projects below the foundation so that the wheel revolves partly in a pit or depression the fan is said to be a three-quarter housed fan. If the outlet is at the top of the housing the fan is a top outlet fan, and if at the bottom, the fan is a bottom outlet fan. And finally, if the discharge is downward, the fan is a down discharge; if upward, an up discharge; and if horizontal, a horizontal discharge.

FIG. 9.—ECONOMIZER, CLARK THREAD CO., NEWARK, N. J.
(Green Fuel Economizer Co.)

Thus the fan in Fig. I has one inlet, all of the housing is above the foundation, the outlet is at the bottom of the housing, and the outlet is placed so that the discharge is in a horizontal direction, and hence the fan is a "full housed, single admission, bottom, horizontal discharge fan." Fans are sometimes made with two outlets as shown in Fig. II, and are then called double discharge fans. Such fans, however, are not used with mechanical draft apparatus, but are used very largely with heating and ventilating apparatus.

The different manufacturers of fans designate their fans according to a number which is approximately equal to the height in inches of a full housed, top, horizontal discharge fan. The size of the housing, however, has little to do with the working of the fan, as that depends altogether upon the diameter and proportions of the wheel put in the housing. For a given diameter of wheel and a given diameter of inlet the width of a fan wheel may be varied between very wide limits and not affect the working of the fan at all. The width of the wheel of what is known as a standard fan is usually about one-half the diameter of the wheel.

The diameter of the inlet of a fan is almost

always in the case of fans used for mechanical draft work, equal to 0.707 of the diameter of the wheel, although sometimes it is 0.625 the diameter of the wheel. The fan with an inlet equal to 0.625 of the diameter of the wheel will handle less air for a given diameter of wheel than a fan for which the diameter of the inlet is 0.707 of the diameter of the wheel. To supply the same volume of air when working against the same pressure or draft, a fan whose ratio of diameter of inlet to diameter of wheel is 0.625 will have a larger wheel than a fan in which the ratio is 0.707; but the first fan will do the required work slightly more efficiently: that is, it will require somewhat less power to run the fan, although the difference will be small. The housing of the fan with the smaller ratio of diameter of inlet to diameter of wheel may not occupy any more space than the housing of the fan with the larger ratio.

Relation Between Revolutions of Fan and Draft. The formulas used in this work are obtained from the general formulas for centrifugal fans given in the work by the author previously referred to.

Let V be the velocity in feet per minute of a

gas whose density is *d;* and *p,* the pressure in ounces per square inch corresponding to this velocity, then

$$(12) \qquad V = 1444 \sqrt{\frac{p}{d}}$$

For some reason not known to the author, pressures or drafts against which fans work are usually expressed in ounces per square inch, but the author thinks that in mechanical draft work, it is better to express the draft produced by a fan in inches of water. Hence, since a pressure or draft of one ounce per square inch is equivalent to 1.73 inches of water, if we let *i* represent, as before, the draft or pressure of a moving gas we have

$$p = \frac{i}{1.73}, \text{ and from } (12)$$

$$(13) \qquad V = 1100 \sqrt{\frac{i}{d}}$$

The greatest pressure or draft which a fan can produce is that corresponding to the velocity in feet per minute of the tips of the floats or blades of the fan wheel. And if *D* be the diameter of the wheel in feet, and *N* the number of revolutions made per minute by the wheel, the velocity in feet per minute of the tips of the

floats will be πDN. Hence, we have from (13)

$$(14) \qquad \pi DN = 1100 \sqrt{\frac{i}{d}}$$

From which we have

$$(15) \qquad DN = 350 \sqrt{\frac{i}{d}}$$

Equation (15) shows, what has been said before, that in order to produce a given draft a fan of a given diameter must be run at a higher velocity when handling hot gases having a low density, than when handling cold air having a higher density.

The fan of a forced draft apparatus handles air at rather a low temperature, seldom exceeding 80 or 85 degrees, so that the value of *d* may be taken as about 0.073, the density of air at a temperature of about 85 degrees.

The fan of an induced draft apparatus *with* an economizer handles gases whose temperature may be as high as 300 or 350 degrees, and the value of *d* may be taken as about 0.050, the density of air at a temperature of about 335 degrees.

The fan of an induced draft apparatus *without* an economizer must ordinarily handle the gases of combustion at a temperature between 500 and

600 degrees, so that the value of d may be taken as about 0.039, the density of air at a temperature of about 560 degrees.

If we put now these values of d in (15) we have

$$DN = \begin{cases} 1295\sqrt{i}, & \text{for forced draft;} \\ 1565\sqrt{i}, & \text{for induced draft with economizer;} \\ 1775\sqrt{i}, & \text{for induced draft without economizer.} \end{cases}$$

For all practical purposes it is exact enough to say

$$(16)\quad DN = \begin{cases} 1300\sqrt{i}, & \text{for forced draft;} \\ 1600\sqrt{i}, & \text{for induced draft with economizer;} \\ 1800\sqrt{i}, & \text{for induced draft without economizer.} \end{cases}$$

Capacity of Fan. The capacity of a fan is the greatest amount of air in cubic feet per minute it will deliver while maintaining a pressure in the housing equal to that corresponding to the velocity of the tips of the floats of the fan wheel. And a fan is said to be working within capacity when the amount of air handled by it is equal to or less than its capacity. As long as a fan is working within its capacity, the pressure or

draft produced by it is equal to that corresponding to the velocity of the tips of the floats of the wheel. When a fan is working within or at its capacity, the theoretical outlet, if the fan be blowing, or the theoretical inlet, if it be sucking, is equal to what is called the "blast area" of the fan. By making the theoretical outlet in the case of a blower or the theoretical inlet in the case of an exhauster, greater than the "blast area" the fan can be made to deliver more air than when working at its capacity, but then the fan will be working at a less efficiency. On the score of economy, a matter of much importance in mechanical draft apparatus, it is not advisable to work a fan beyond its capacity.

Let A be the capacity of the fan; r the ratio obtained by dividing the diameter of the inlet by the diameter of the fan wheel; D the diameter of the fan wheel in feet; and N the number of revolutions at which the fan is run. Then

$$(17) \qquad A = 1.38\, r^3 D^3 N$$

A double admission fan would have a capacity equal to twice that of a single admission fan with an overhung wheel, were it not that usually the inlets are so obstructed by the shaft and its bearings, and the driving pulley on one side, that

the sum of free and unobstructed areas of the two inlets of a double admission fan is seldom much if any greater than the area of the single inlet of a single admission fan of the same size.

As has been said before, the usual value of r for fans used for mechanical draft is 0.707, and if this value be put in (17) we have

$$(18) \qquad A = 0.49\, D^3 N$$

If in (18) we put for DN its value as given in (16) we have:

For forced draft,

$$(19) \qquad A = 640\, D^2 \sqrt{i}$$

For induced draft with an economizer,

$$(20) \qquad A = 780\, D^2 \sqrt{i}$$

For induced draft without an economizer,

$$(21) \qquad A = 880\, D^2 \sqrt{i}$$

CHAPTER VIII.

PROPORTIONING THE PARTS.

Diameter of Fan Wheel Required. From what has been said before it is known that the air to be handled per minute for the combustion of C pounds of coal per hour with a forced draft is $4C$. So putting in (19) this value of A and solving for C we have for the relation between the pounds of coal burned per hour and the diameter of the fan wheel for forced draft,

$$(22) \qquad C = 160D^2 \sqrt{i}$$

Since the gases to be handled per minute for the combustion of C pounds of coal with an induced draft apparatus with an economizer is $6C$, by substituting $6C$ for A in (20) and solving for C, we have for the relation between the pounds of coal burned per hour and the diameter of the fan wheel of an induced draft apparatus *with* an economizer,

$$(23) \qquad C = 130D^2 \sqrt{i}$$

And since the gases to be handled per minute for the combustion of C pounds of coal per hour with an induced draft apparatus without an economizer is $8C$, by substituting $8C$ for A in (21) and solving for C, we have for the relation between the pounds of coal burned per hour and the diameter of the fan wheel of an induced draft apparatus *without* an economizer,

$$(24) \qquad C = 110D^2 \sqrt{i}$$

Table XIII, calculated from (22), shows the number of pounds of coal that can be burned per hour with a forced draft apparatus when the fan is run at a speed corresponding to different pressures in the ash-pit.

Table XIV, calculated from (23), shows the number of pounds of coal that can be burned per hour with an induced draft apparatus *with* an economizer when the fan is run at a speed corresponding to different drafts.

Table XV, calculated from (24), shows the number of pounds of coal which can be burned per hour with an induced draft apparatus *without* an economizer when the fan is run at a speed corresponding to different drafts.

TABLE XIII.

Relation between Size of Fan and Weight of Coal Burned per Hour for Forced Draft.

Diameter of wheel in feet	Pressure in ash-pit in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	910	1020	1110	1200	1440	1610	1760	2040	2280	2500
3½	1160	1300	1420	1640	1840	2050	2250	2600	2900	3000
4	1620	1810	1980	2140	2600	2900	3100	3600	4000	4400
4½	2050	2290	2500	2900	3200	3600	4000	4600	5100	5600
5	2500	2800	3100	3600	4000	4500	4900	5700	6300	6900
5½	3100	3400	3800	4300	4800	5400	5900	6900	7700	8400
6	3600	4100	4500	5200	5800	6400	7100	8100	9100	10000
6½	4300	4800	5200	6100	6800	7600	8300	9600	10700	11700
7	5000	5500	6100	7000	7800	8800	9600	11100	12400	13600
8	6500	7200	7900	9200	10200	11400	12500	14500	16200	17700
9	8200	9200	10000	11600	13000	14500	15900	18300	20500	22500
10	10100	11300	12400	14300	16000	17900	19600	22600	25000	28000
11	12200	13700	15000	17300	19400	21700	24700	27000	31000	34000
12	14600	16300	17800	20600	23000	26000	28000	33000	36000	40000

FIG. 10.—INDUCED DRAFT APPARATUS, BAY CITY TRACTION AND ELECTRIC CO., BAY CITY, MICH. (B. F. Sturtevant & Co.)

TABLE XIV.

Relation between Size of Fan and Weight of Coal Burned per Hour for Induced Draft with an Economizer.

Diameter of wheel in feet.	Draft in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	740	830	910	1040	1170	1310	1430	1650	1850	2030
3½	1010	1120	1230	1420	1590	1780	1950	2250	2520	2800
4	1310	1470	1610	1860	2080	2320	2500	2900	3300	3600
4½	1660	1850	2040	2360	2600	2900	3200	3700	4200	4600
5	2060	2300	2500	2900	3200	3600	4000	4600	5100	5600
5½	2480	2800	3000	3500	3900	4400	4800	5600	6200	6800
6	3000	3300	3600	4200	4700	5200	5700	6600	7400	8100
6½	3500	3900	4300	4900	5500	6100	6700	7800	8700	9500
7	4000	4500	4900	5700	6400	7100	7800	9000	10100	11000
8	5300	5900	6400	7400	8300	9300	10200	11700	13100	14400
9	6600	7400	8100	9400	10500	11700	12900	14900	16600	18200
10	8200	9200	10100	11600	13000	14500	15900	18400	20600	22500
11	9900	11100	12200	14100	15700	17600	19200	22300	24800	27000
12	11800	13200	14500	16800	18700	20900	22900	26500	29600	32400

TABLE XV.

Relation between Size of Fan and Weight of Coal Burned per Hour for Induced Draft without an Economizer.

Diameter of wheel in feet.	Draft in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	630	710	770	890	900	1110	1210	1400	1560	1710
3½	850	950	1050	1210	1350	1500	1650	1900	2130	2330
4	1110	1240	1360	1570	1760	1960	2160	2490	2780	3050
4½	1410	1580	1730	1990	2230	2500	2700	3200	3500	3900
5	1740	1950	2130	2460	2800	3100	3400	3900	4300	4800
5½	2110	2360	2600	3000	3300	3700	4100	4700	5300	5800
6	2500	2800	3100	3500	4000	4400	4900	5600	6300	6900
6½	2900	3300	3600	4200	4600	5200	5700	6600	7400	8100
7	3400	3800	4200	4800	5400	6000	6600	7600	8500	9300
8	4400	5000	5500	6300	7000	7900	8600	10000	11100	12200
9	5600	6300	6900	8000	8900	10000	10900	12600	14100	15400
10	7000	7800	8500	9800	11000	12300	13500	15600	17400	19000
11	8400	9400	10300	11900	13300	14900	16300	18800	21000	23000
12	10000	11200	12200	14100	15800	17700	19400	22400	25000	27000

The use of the tables may be illustrated by an example.

Example. Determine the diameter of a wheel of a fan for an induced draft apparatus with an economizer to burn 4500 pounds of coal per hour under a draft of about 0.8 of an inch.

Turning to Table XIV we see that a 6½-foot wheel is more than large enough for 4500 pounds of coal an hour under a draft of 0.8 of an inch, and that a 5-foot wheel is large enough under a draft of 2 inches. The 5-foot wheel would cost more to run, because it would require more power than the 6½-foot wheel.

Speed at which the Fan must be Run. When the pressure or draft and the diameter of the wheel have been determined, it is then necessary to determine the number of revolutions at which the wheel must be run in order to give the required draft.

For a forced draft we get from (16)

$$N = \frac{1300 \sqrt{i}}{D}$$

This equation has been used to calculate Table XVI, which gives the number of revolutions per minute that wheels of various diameters used

for forced draft, must make in order to give different pressures in inches of water.

For an induced draft apparatus *with* an economizer we have from (16)

$$N = \frac{1600\sqrt{i}}{D}$$

This equation has been used to calculate Table XVII, which gives the number of revolutions that must be made per minute by the wheels of induced draft fans *with* economizers in order to give different drafts in inches of water.

We have from (16) for an induced draft fan *without* an economizer

$$N = \frac{1800\sqrt{i}}{D}$$

This equation has been used to calculate Table XVIII, which gives the number of revolutions that must be made per minute by the wheels of induced draft fans *without* economizers in order to give different drafts in inches of water.

Power Required to Run the Fan. From the author's work on fans previously referred to

TABLE XVI.

Revolutions per Minute of Fan Wheel for Forced Draft.

Diameter of wheel in feet.	Pressure in ash-pit in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	275	305	335	390	335	485	530	615	685	750
3½	235	265	290	335	370	415	455	525	585	645
4	205	230	250	290	325	365	400	460	515	565
4½	185	205	225	260	290	325	355	410	455	500
5	165	185	200	230	260	290	320	370	410	450
5½	150	170	185	210	235	265	290	335	375	410
6	140	155	170	195	215	240	265	305	340	375
6½	125	140	155	180	200	225	245	285	315	345
7	120	130	145	165	185	210	225	265	295	320
8	105	115	125	145	165	180	200	230	255	280
9	90	102	112	130	145	160	175	205	230	250
10	83	92	100	115	130	145	160	185	205	225
11	75	84	92	106	120	132	145	167	187	205
12	70	77	84	97	110	120	133	153	170	190

TABLE XVII.

Revolutions per Minute of Fan Wheel for Induced Draft with an Economizer.

Diameter of wheel in feet.	Draft in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	340	375	415	475	535	595	655	755	845	925
3½	290	325	355	410	455	510	560	645	725	795
4	255	280	310	360	400	445	490	565	635	695
4½	225	250	275	320	355	395	435	505	565	615
5	205	225	250	285	320	360	390	450	505	555
5½	185	205	225	260	290	325	355	410	460	505
6	170	190	205	240	265	300	325	375	425	460
6½	155	175	190	220	245	275	300	350	390	425
7	145	160	175	205	230	255	280	325	360	395
8	127	140	155	180	200	225	245	280	315	345
9	113	125	140	160	180	200	220	250	280	310
10	101	113	125	145	160	180	195	225	255	275
11	92	103	113	130	145	165	180	205	230	250
12	85	94	104	120	133	150	165	190	210	230

TABLE XVIII.

Revolutions per Minute of Fan Wheel for Induced Draft without an Economizer.

Diameter of wheel in feet.	Draft in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	380	425	465	535	600	670	735	850	950	1040
3½	325	365	400	460	515	575	630	730	815	890
4	285	320	350	405	450	505	550	635	710	780
4½	255	285	310	360	400	445	490	565	635	695
5	230	255	280	320	360	400	440	510	570	625
5½	210	230	255	295	330	365	400	465	520	565
6	190	210	230	270	300	335	365	425	475	520
6½	175	195	215	250	255	310	340	390	440	480
7	165	180	200	230	260	285	315	365	405	445
8	140	160	175	200	225	250	275	320	355	390
9	127	140	155	180	200	225	245	285	315	345
10	114	128	140	160	180	200	220	255	285	310
11	104	115	127	145	165	185	200	230	260	285
12	95	106	117	135	150	170	185	210	235	260

we get that the horse power, H, required to drive a fan when working at its capacity is

$$(25) \qquad H = \frac{A\,p\,(1 + r^2)}{3300}$$

In this equation A is the cubic feet of air or gas handled per minute; p, the pressure in ounces per square inch corresponding to the velocity of the tips of the floats of the wheel; and r, as before, is the ratio of the diameter of the inlet divided by the diameter of the wheel. If we put for p its value $\frac{i}{1.73}$ and for r the value generally found in fans, 0.707, we get

$$(26) \qquad H = \frac{A\,i}{3800}$$

For forced draft we know that A is equal to $4C$, where C is the weight of coal burned per hour. Hence if we put in (26) for A its value, we get for *forced draft*,

$$(27) \qquad H = \frac{C\,i}{950}$$

For induced draft with an economizer we know

that A is equal to $6C$ and hence we have from (26) for *induced draft with an economizer,*

$$(28) \qquad H = \frac{C\,i}{635}$$

For induced draft without an economizer we know that A is equal to $8C$; and hence we have from (26) for *induced draft without an economizer,*

$$(29) \qquad H = \frac{C\,i}{475}$$

If we put for C in (27) its value as given by (22), we have for *forced draft fans,*

$$(30) \qquad H = \frac{D^2 \sqrt{i^3}}{5.9}$$

Table XIX has been calculated from (30). It gives the horse power required to drive forced draft fans when working at their capacity under different pressures in inches of water.

If we put for C in (28) its value as given by (23), we have for induced draft fans *with economizers,*

$$(31) \qquad H = \frac{D^2 \sqrt{i^3}}{4.8}$$

TABLE XIX.

Horse Power Required for Fans for Forced Draft.

Diameter of wheel in feet.	Pressure in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	0.38	0.54	0.70	1.0	1.5	2.1	2.8	4.3	6.0	7.9
3½	0.49	0.68	0.90	1.4	1.9	2.7	3.6	5.5	7.6	10.1
4	0.68	0.95	1.3	1.8	2.7	3.8	4.9	7.6	10.5	13.9
4½	0.86	1.2	1.6	2.4	3.4	4.7	6.3	9.7	13.4	17.7
5	1.1	1.5	2.0	3.0	4.2	5.9	7.7	12.0	16.6	21.8
5½	1.3	1.8	2.4	3.6	5.1	7.1	9.3	14.5	20.3	26.5
6	1.5	2.2	2.8	4.4	6.1	8.4	11.2	17.0	23.9	31.6
6½	1.9	2.5	3.3	5.1	7.2	10.0	13.1	20.2	28.1	36.9
7	2.1	2.9	3.9	5.9	8.2	11.6	15.1	23.4	32.6	42.9
8	2.7	3.8	5.0	7.8	10.7	15.0	19.7	30.5	42.6	55.8
9	3.5	4.8	6.3	9.8	13.7	19.1	25.1	38.5	53.8	71.0
10	4.3	5.9	7.8	12.0	16.8	23.6	30.9	47.6	65.7	88.4
11	5.1	7.2	9.5	14.5	20.4	28.5	39.0	56.8	81.5	107.0
12	6.2	8.6	11.2	17.3	24.2	34.2	44.2	69.5	94.6	126.0

Fig. 11.—Induced Draft Apparatus, Hudson River Electric Power Co., Utica, N. Y. (American Blower Co.)

TABLE XX.

Horse Power Required for Fans for Induced Draft with an Economizer.

Diameter of wheel in feet.	Draft in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	0.47	0.65	0.86	1.3	1.8	2.6	3.4	5.2	7.3	9.6
3½	0.64	0.88	1.2	1.8	2.5	3.5	4.6	7.1	9.9	13.2
4	0.83	1.2	1.5	2.3	3.3	4.6	5.9	9.1	13.0	17.0
4½	1.1	1.5	1.9	3.0	4.1	5.7	7.6	11.7	16.6	21.7
5	1.3	1.8	2.4	3.7	5.0	7.1	9.5	14.5	20.5	26.5
5½	1.6	2.2	2.8	4.4	6.1	8.7	11.4	17.6	24.4	32.1
6	1.9	2.6	3.4	5.3	7.4	10.2	13.5	20.8	29.1	38.3
6½	2.2	3.1	4.1	6.2	8.7	12.0	15.8	24.7	34.3	44.9
7	2.5	3.5	4.7	7.2	10.1	14.0	18.4	28.3	39.8	52.0
8	3.3	4.6	6.1	9.3	13.1	18.3	24.1	36.8	51.6	68.0
9	4.2	5.8	7.7	11.9	16.5	23.0	30.5	46.9	65.4	86.0
10	5.2	7.3	9.9	14.6	20.5	28.5	37.6	58.0	81.1	106.0
11	6.2	8.7	11.5	17.8	24.7	34.7	45.3	70.3	97.7	128.0
12	7.5	10.4	13.7	21.2	29.4	41.2	54.1	83.5	117.0	148.0

TABLE XXI.

Horse Power Required for Fans for Induced Draft without an Economizer.

Diameter of wheel in feet.	Draft in inches of water.									
	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
3	0.53	0.75	0.97	1.5	2.1	2.9	3.8	5.9	8.2	10.8
3½	0.72	1.0	1.2	2.0	2.8	4.0	5.2	8.0	11.2	14.7
4	0.93	1.3	1.7	2.6	3.7	5.2	6.8	10.5	14.6	19.3
4½	1.2	1.7	2.2	3.4	4.7	6.6	8.5	13.5	18.4	24.6
5	1.5	2.1	2.7	4.1	5.9	8.2	10.8	16.4	22.6	30.3
5½	1.8	2.5	3.3	5.1	7.0	9.8	13.0	19.8	27.9	36.6
6	2.1	3.0	3.9	5.9	8.4	11.6	15.5	23.6	33.2	43.6
6½	2.4	3.5	4.6	7.1	9.7	13.7	18.0	27.8	39.0	51.2
7	2.9	4.0	5.3	8.1	11.4	15.8	20.8	32.0	44.7	58.7
8	3.7	5.3	7.0	10.6	14.7	20.8	27.2	42.1	58.4	77.2
9	4.7	6.6	8.7	13.5	18.8	26.3	34.4	53.0	74.3	97.5
10	5.9	8.2	10.7	16.5	23.1	32.4	42.6	65.7	91.6	120.0
11	7.1	9.9	13.0	20.0	28.0	39.2	51.5	79.2	110.0	145.0
12	8.4	11.8	15.4	23.8	33.2	46.6	61.2	94.3	132.0	171.0

Table XX has been calculated from (31). It gives the horse power required to drive induced draft fans *with* economizers when working at their capacity under different drafts in inches of water.

If we put for C in (29) its value as given by (24), we have for induced draft fans *without* economizers,

$$(32) \qquad H = \frac{D^2 \sqrt{i^3}}{4.3}$$

Table XXI has been calculated from (32). It gives the horse power required to drive induced draft fans *without* economizers when working at their capacity under different drafts in inches of water.

Size of Engine Required. The indicated horse power of the engine is, as has been said before, equal to about 1.5 times the horse power required to drive the fan, or 1.5 times the value of H as given by (30) for forced draft, or by (31) for induced draft with an economizer, or by (32) for induced draft without an economizer.

From (16), (30), (31), and (32), we get

$$(33)\quad 1.5\,H = \begin{cases} \dfrac{1.5\,D^3Ni}{5.9 \times 1300}, & \text{for forced draft.} \\[2ex] \dfrac{1.5\,D^3Ni}{4.8 \times 1600}, & \text{for induced draft with an economizer.} \\[2ex] \dfrac{1.5\,D^3Ni}{4.3 \times 1800}, & \text{for induced draft without an economizer.} \end{cases}$$

$$= \frac{D^3Ni}{5150}, \text{ for all.}$$

From the well known formulas in regard to steam engines it is known that if P is the mean effective pressure of the steam in the cylinder; l, the stroke, in inches, of the engine; d, the diameter, in inches, of the cylinder; and N, the number of revolutions made per minute by the engine; the indicated horse power of the engine is $\frac{Pld^2N}{252000}$. In the case of an engine direct connected to a fan the number of revolutions, N, made by the engine is the same as the number of revolutions made by the fan.

But as has been said, $1.5H$ is equal to the indicated horse power developed by the engine, and hence for direct connected engines.

$$\frac{Pl\,d^2N}{252\,000} = \frac{D^3Ni}{5150}$$

From this we get

$$(34) \qquad l\,d^2 = \frac{49\,D^3i}{P}$$

The direct connected engines ordinarily used to drive the fans of a mechanical draft apparatus cut off at ¾ stroke, so that the mean effective pressure, *P*, when the boiler pressure is about 100 pounds by the gage, may safely be taken between 80 and 90. If we say *P* is equal to 80, (34) becomes,

$$(35) \qquad l\,d^2 = 0.61\,D^3i$$

In these engines the stroke varies from 1 to 1.5 times the diameter, but is seldom if ever greater than 1.5 times the diameter. If in (35) we substitute *d* for *l* and solve for *d* we get the expression for the diameter of the engine required

for the fan when the stroke is equal to the diameter,

$$(36) \qquad d = 0.85\, D \sqrt{i}$$

Table XXII gives the value of $0.85 \sqrt{i}$ for different volues of i.

TABLE XXII.

Values of $0.85 \sqrt[3]{i}$

i	$0.85 \sqrt[3]{i}$
0.5	0.67
1.0	0.86
1.5	0.96
2.0	1.06
2.5	1.14
3.0	1.21

This table shows plainly that the common rule-of-thumb for determining the diameter of the direct connected engine for a fan to give a draft of from 1 to 1.5 inches of water is correct. The rule is: Make the diameter of the engine in inches about the same as, but not less than three-quarters, the diameter of the fan wheel in feet, and make the stroke greater than the diameter.

Instead of using Table XXII to determine the size of engine required, equation (35) may be used in connection with Table XXVII in the Appendix.

Steam Used by Fan Engine. The fan engines being rather inefficient and cutting off between one-half and three-quarters stroke, use a great deal of steam per hour per indicated horse power, so that this steam used by them may be a considerable per cent of the whole capacity of the plant unless care be taken in designing the apparatus to keep the consumption within a certain limit. It is probable that the steam used per indicated horse power by the fan engines will not be far from 40 to 50 pounds per hour. And as the indicated horse power is probably not far from 1.5 the power required to run the fans as given by Table XIX for forced draft; Table XX for induced draft with an economizer; and Table XXI for induced draft without an economizer, we may say that the weight of steam required per hour to run a fan is equal to the power as given by the proper table multiplied by 70.

Choosing the Fan. When designing a me-

chanical draft plant it is important to know,

(a) The kind of mechanical draft, *i. e.,* forced. induced *with* economizer, or induced *without* economizer.

(b) The kind of coal to be used, and the rate of combustion per hour per square foot of grate surface.

(c) The maximum weight of coal to be burned per hour, and the probable actual evaporation of water per pound of coal.

(d) The maximum per cent of the steam generated that may be used per hour to run the fan engine.

Knowing these conditions we determine the minimum allowable draft, which is the draft necessary for the combustion of the given kind of coal at the required rate. Then by the use of the various tables we determine the diameter of the fan wheel which for the kind of draft has a capacity equal to the maximum weight of coal to be burned per hour, when using not more steam than is allowed by the conditions of the problem.

The course to be followed when choosing a fan for a given set of conditions can be best illustrated by an example.

Example. Determine the proper size of fan to

be used for an induced draft plant without an economizer to burn 6,000 pounds of coal per hour at a maximum rate of 24 pounds of coal per hour per square foot of grate surface. The coal is of a low grade bituminous, approaching the condition of slack; and the steam used to run the fan must not exceed 2½ per cent of the steam made by the plant.

From Table VIII we see that a draft of 0.81 of an inch is necessary for the combusion of 25 pounds of bituminous slack per hour per square foot of grate surface, and hence we may assume that the draft under which the fan must work must not be less than 0.8 of an inch.

It is probable that the total water evaporated per hour under actual conditions will be about 35,000 pounds. And 2½ per cent of this is 825 pounds, which is the weight of steam the engine may use to drive the fan. Assuming 70 pounds of water per hour per horse power, we have that the horse power to drive the fan must not exceed,

$$\frac{825}{70} = 11.8$$

Turning now to Table XV we see that we may use an 8-foot wheel at a draft of 0.8 of an inch or a 7-foot wheel at a draft of 1.25

inches. From Table XXI we see that a 10.6 horse power will be required to run the 8-foot wheel at a draft of 0.8 of an inch, and 15.8 horse power will be required to run the 7-foot wheel at a draft of 1.25 inches.

However, let us suppose that we choose the 8-foot fan. We now turn to Table XVIII and find that this fan must be run at a speed of 200 revolutions per minute to give a draft of 0.8 of an inch.

Turning now to Table XXII we see that for the 8-foot fan, we may use an engine whose cylinder diameter in inches is between 0.86 and 0.67 of the diameter of the wheel in feet. That is, a 7 by 7 or a 6 by 9 engine is large enough.

The process then to be followed to choose a proper fan is as follows:

For Forced Draft.

1 — From Table X determine the pressure which must be maintained in the ash-pit for the combustion of the given kind of coal at the required maximum rate.

2 — From Table XIII choose a fan which is large enough for the maximum weight of coal to be burned when working at a pressure not less than that required by Table X.

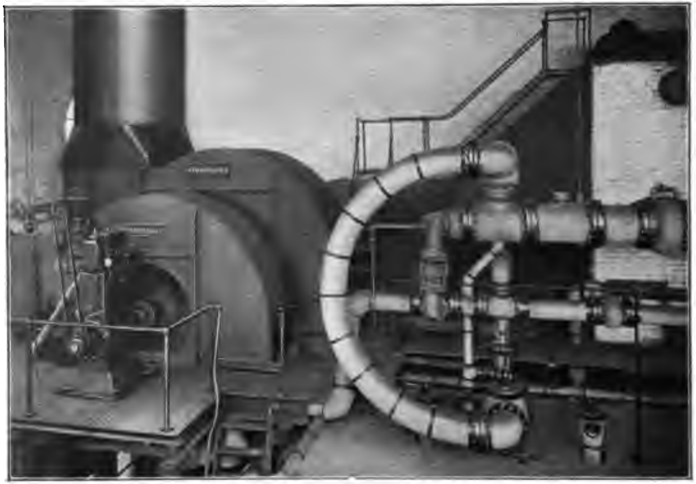

Fig. 12.—Economizer and Induced Draft Apparatus, B. F. Sturtevant Co., Hyde Park, Mass.
(B. F. Sturtevant Co.)

3 — From Table XVI determine the number of revolutions the fan must make per minute.

4 — From Table XIX determine the power required to run the fan.

5 — Find by the aid of Table XXII the diameter of the cylinder of the engine required.

6 — Multiply the horse power by 70 to get the weight of steam required per hour to run the fan.

For Induced Draft With Economizer.

1 — From Table IX find the draft required for the given kind of coal and rate of combustion.

2 — From Table XIV choose a fan large enough for the maximum rate of coal to be burned per hour when working at a draft not less than that required by Table IX.

3 — From Table XVII determine the number of revolutions the fan must make per minute.

4 — From Table XX determine the horse power required to run the fan.

5 — Find by the aid of Table XXII the diameter of the cylinder of the engine required.

6 — Multiply the horse power by 70 to get the weight of steam required per hour to run the engine.

For Induced Draft Without Economizer.

1 — From Table VIII find the draft required for the given kind of coal and rate of combustion.

2 — From Table XV choose a fan large enough for the maximum weight of coal to be burned per hour when working at a draft not less than that required by Table VIII.

3 — From Table XVIII determine the number of revolutions the fan must make per minute.

4 — From Table XXI determine the horse power required to run the fan.

5 — Find by the aid of Table XXII the diameter of the cylinder of the engine required.

6 — Multiply the horse power by 70 to get the weight of steam required per hour to run the engine.

It may often happen that the maximum weight of coal to be burned per hour by a plant will be that which will be required only a few days during the year. It may well occur in the case of a plant that supplies steam for power and heating purposes, that an unusual amount of steam may be required for possibly a week or two during the severe weather of the winter and the rest of the year the amount of coal that is required to

be burned may not be more than two-thirds or three-quarters of the maximum amount. In a case of this kind it will usually be economy to put in a fan sufficiently large to take care of the normal amount and when the excessive demand comes upon the plant, speed the fan up or run both fans. It is, of course, to be understood that in all cases where an induced draft system is installed, the fans are to be installed in duplicate and one fan should be sufficient to take care of the plant with probably 20 to 25 per cent more than the normal condition of combustion; and whenever the requirements of the plant demand more than one fan can do, both fans may be run.

Location of the Fans. No general rule can be given as to where the fans of a mechanical draft apparatus should be located, as this will depend upon the arrangement of the boilers in the boiler house. The fans, however, may be put on the floor or near the roof, but in every case they should be convenient of access so that the engines can be attended to.

Breeching and Uptake. The breeching and uptake connections between the boilers and the chimney of a closed ash-pit system of mechanical

draft should be proportioned just as for an ordinary system of chimney draft.

In the case of a system of induced draft it is usual to make the breeching and uptake connections somewhat smaller than for a chimney draft of the same intensity, probably because if a higher draft should be needed it is so very easy to get it by speeding up the fans, in the case of mechanical draft, while in the case of a chimney draft the only way to increase the intensity of the draft for a given set of conditions as to temperature of outside air and gases inside, is to make the chimney higher.

In no case should the area of the breeching leading to the fan be of a less area than the inlet of the fan, and in most cases it is well to make it larger. The area of the breeching should be made greater in proportion to the area of the inlet for small than for large fans. It is extremely difficult to get data as to the proper sizes of breeching to be used with different sizes of fans, and in fact the size of the breeching should be made to depend not upon the size of fan but rather upon the number of pounds of coal to be burned per hour. If the length of the breeching, the number of turns and bends, and the other resistances to the flow of gases are known it

would be a very simple matter to design a breeching so that the resistance due to friction may be a certain predetermined amount. Unfortunately it is next to impossible to proportion breechings in this way, and hence other methods must be resorted to.

After as careful a study of the subject as the data available would allow, the author has calculated Table XXIII to be used when proportioning the breeching and uptake connections. The table is based upon the weight of coal to be burned per hour and the draft to be given by the fan, and is intended primarily for induced mechanical draft systems having square or nearly square breeching and uptake connections. If the breeching or uptake is to be round it should have a diameter one-tenth greater than the side of the square given in the table, since a circle whose diameter is 10 per cent greater than the side of a given square offers the same resistance to the flow through it of a given volume of gases per hour as the square, although the area of the cross-section of the circle is about 5 per cent less than that of the square.

The use of the table can best be shown by an example.

Example. Determine the size of breeching

and uptake connections for an induced system of mechanical draft for four boilers each having a furnace capable of burning 1,500 pounds of coal per hour under a draft of 1.25 inches of water.

Here the draft is 1.25 inches, and the total coal to be burned per hour is 6,000 pounds. Hence we look in Table XXIII down the column showing a draft of 1.25 inches until we find 6,000, and then find the side of the square in the first column opposite 6,000. We find that the breeching between the four boilers and the fan should be a square whose side is 62 inches and whose area is 3,844 square inches. If the breeching be round the diameter should be about 68 inches.

Three of the boilers will have burned under them a total of 4,500 pounds of coal per hour. Again looking down the column showing a draft of 1.25 inches we find that a square breeching whose side is 54 inches and whose area is 2,916 square inches is large enough for 4,400 pounds of coal per hour, and hence we may use this as the size of the breeching between the third and fourth boilers.

The breeching between the second and third boilers must be large enough to take care of 3,000 pounds of coal per hour under a draft of 1.25 inches of water. The table shows that we may

use here a square whose side is 46 inches and whose area is 2,116 square inches, as it will be large enough to take care of 3,100 pounds of coal per hour.

The breeching between the first boiler and the second must be large enough to take care of 1,500 pounds of coal per hour under a draft of 1.25 inches of water and the table shows that if it be square its side should be 34 inches and its area of cross-section should be 1,156 square inches.

Since the uptake connection from each boiler to the breeching is to be large enough to take care of 1,500 pounds of coal per hour under a draft of 1.25 inches of water, we should give each an area of 1,156 square inches, and make it as nearly square as possible.

When an economizer is used, the breeching and uptake connections should be larger for the same *total* draft and the same weight of coal to be burned per hour than when an economizer is not used, because about one-third of the total draft will be used to overcome the friction due to the economizer. A safe rule and in fact one that will probably give sizes a little large, is to proportion the breeching and uptake connections when an

economizer is used, for a draft that is two-thirds of the total draft.

Inlet Chamber. When two fans are installed in a mechanical draft plant as is usual, the breeching from the boiler is lead into a chamber, called the "inlet chamber," which is usually placed between the two fans, and from which they draw the gases of combustion. This chamber should be provided with a heavy damper by means of which the inlet of either fan may be closed, thus putting that particular fan out of service by preventing the gases from entering it.

Provision should always be made for fastening the damper in mid-position, so that both fans may handle gases, or in such a position as to shut off either fan.

Discharge Chimney. In the case of a closed ash-pit system of mechanical draft the chimney should be high enough to give a draft not less than 0.4 of the total draft required for the combustion of the given amount of coal at the desired rate in pounds per square foot per hour, and the cross-section of the chimney must be sufficient to discharge the gases under this draft.

In the case of an induced system of mechanical draft the discharge chimney need not be any

TABLE XXIII.

Breeching and Uptake Connections for Induced Draft with Various Drafts in Inches of Water and Different Weights of Coal Burned per Hour.

Breeching or uptake.		Draft in inches of water.									
Side of square, inches	Area of cross-section square inches	0.4	0.5	0.6	0.8	1.00	1.25	1.50	2.00	2.50	3.00
30	900	630	710	770	890	990	1110	1210	1400	1560	1710
34	1156	850	950	1050	1210	1350	1500	1650	1900	2130	2330
38	1444	1110	1240	1360	1570	1760	1960	2160	2490	2780	3050
42	1764	1410	1580	1730	1990	2230	2500	2700	3200	3500	3900
46	2116	1740	1950	2130	2460	2800	3100	3400	3900	4300	4800
50	2500	2110	2360	2600	3000	3300	3700	4100	4700	5300	5800
54	2916	2500	2800	3100	3500	4000	4400	4900	5600	6300	6900
58	3364	2900	3300	3600	4200	4600	5200	5700	6600	7400	8100
62	3844	3400	3800	4200	4800	5400	6000	6600	7600	8500	9300
68	4624	4400	5000	5500	6300	7000	7900	8600	10000	11100	12200
74	5476	5600	6300	6900	8000	8900	10000	10900	12600	14100	15400
80	6400	7000	7800	8500	9800	11000	12300	13500	15600	17400	19000
86	7396	8400	9400	10300	11900	13300	14900	16300	18800	21000	23000
92	8464	10000	11200	12200	14100	15800	17700	19,400	22400	25000	27000

higher than is absolutely necessary to discharge the products of combustion into the atmosphere above the surrounding objects or buildings which might be injured by the hot gases. The area of the cross-section of the discharge chimney should not be less than the area of a circle whose diameter is equal to one-half the diameter of the wheel. That is to say, the diameter of the discharge chimney should not be less than one-half the diameter of the wheel, and it must be made greater the higher is the chimney.

Where two fans are to be run together the diameter of the discharge chimney or stack of an induced draft apparatus should not be less than 0.7 of the diameter of the fan wheel.

The connections between the fans and the discharge chimney should be as short and as straight as possible in order to avoid friction.

By-pass. When an induced system of mechanical draft is installed, it may be necessary to put in a " by-pass " or passage through which the gases may pass from the uptake into the chimney without passing through the fan. This by-pass is not always necessary, although in large plants it is customary to put it in. It is never made large enough to take all the gases of the plant when

running at its full capacity, but is usually of such a size that it will take the gases from the plant when running at about 5 or 10 per cent of its capacity. The object of it is to enable steam to be raised in one of the boilers of the plant so that the engines which are to drive the fans may be run.

If the connections between the boilers and the fan are short and the discharge chimney is not high, there is then no necessity for a by-pass, as steam can usually be gotten up in one boiler of the plant, at least, without a by-pass. The pressure to which the steam in the boiler must be raised before the engine driving the fan can be run will depend of course upon the relative size of the fan and the engine driving it. If the engine is fairly large in proportion to the diameter of the fan wheel, there ought to be no trouble in starting the fan when the steam pressure is in the neighborhood of 20 or 25 pounds by the gage. This pressure, of course, will not be sufficient to run the fan at its full capacity, but it will be usually sufficient to start the fan; and as the fan works, the fire under the boiler will burn more rapidly, and the pressure in the boiler will rise, and as the pressure rises the fan will go faster. When the fan has gotten up to its speed,

the fires can be built under the other boilers of the plant, and in this way the whole plant may be set in operation.

When a by-pass is put in the size of it must be determined according to the length and size of the various connections between the boilers and the fan, and will depend very largely upon local conditions, so that it is hardly possible to give a rule for proportioning it. It is one of those things which must depend largely upon the judgment of the engineer.

Water for Bearings. In the case of an induced draft system it is absolutely necessary to have a sufficient quantity of water circulating through the bearings of the fans in order to keep them cool when handling the hot gases. It is almost impossible to predict the amount of water that will be used, as it depends upon the temperature of the gases and the temperature of the cooling water. In every case, however, it is absolutely necessary that the bearings be kept cool, what ever amount of water may be required.

There should be one supply pipe and one return pipe run to each bearing, and as there will be one water-jacketed bearing to each fan that means two water pipes for each fan. Each of

these pipes should be ordinary $\frac{1}{2}$-inch galvanized pipe, and each should be provided with a valve so that any one bearing can be disconnected from the water system without interfering with the other. If the water can be utilized after it has passed through the bearings this should be done; but if it cannot be utilized then it must be allowed to go to waste, and the expense of the water so wasted must be considered as one of the operating expenses of the fan.

APPENDIX.

GENERAL TABLES.

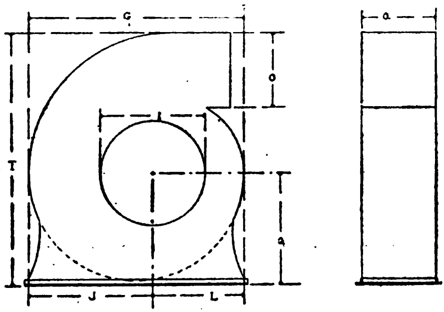

TABLE XXIV.

Dimensions of Full Housed, Top, Horizontal Discharge Fans.

Diameter of wheel in feet.	Dimensions of housings in inches.						
	I	O	G	T	J	L	Q
3	25	18	52	61	30	22	27
3½	30	21	61	71	36	25	31
4	34	24	69	81	40	29	36
4½	38	27	78	91	45	33	40
5	42	30	87	101	50	37	44
5½	47	33	95	110	55	40	49
6	51	36	104	120	60	44	53
6½	55	39	113	130	65	48	57
7	59	42	121	140	70	51	61
8	68	48	139	160	80	59	70
9	76	54	156	180	90	66	79
10	85	60	173	200	100	73	87
11	93	66	191	220	110	81	96
12	102	72	208	240	120	88	105

TABLE XXV.

Thickness of Black Sheet Iron and Steel Usually Used for Breeching, Uptakes, Stacks, etc., in Connection with Mechanical Draft Installations.

United States standard gauge.*	Thickness in decimals of an inch.
8	0.171875
10	0.140625
12	0.109375
14	0.078125
16	0.0625

* Legalized by Congress, March, 1893, as a standard gage for sheet and plate iron and steel. It is used by the Custom House and by most manufacturers of sheet iron and steel.

TABLE XXVI.

Areas of Circles from 10 Inches to 72 Inches in Diameter, given in Square Inches to the nearest Inch.

Diameter.	Area.	Diameter.	Area.	Diameter.	Area.
10	79	31	755	52	2124
11	95	32	804	53	2206
12	113	33	855	54	2290
13	133	34	908	55	2376
14	154	35	962	56	2463
15	177	36	1018	57	2552
16	201	37	1075	58	2642
17	227	38	1134	59	2734
18	254	39	1195	60	2827
19	284	40	1257	61	2922
20	314	41	1320	62	3019
21	346	42	1385	63	3117
22	380	43	1452	64	3217
23	415	44	1521	65	3318
24	452	45	1590	66	3421
25	491	46	1662	67	3526
26	531	47	1735	68	3632
27	573	48	1810	69	3739
28	616	49	1886	70	3848
29	661	50	1964	71	3959
30	707	51	2043	72	4072

TABLE XXVII.

Sizes of Engines Suitable for use with Mechanical Draft Installations.

Vertical.			Horizontal.		
Diameter inches d	Stroke inches l	ld^2	Diameter inches d	Stroke inches l	ld^2
3	4	36	7	10	490
4	5	80	8	10	640
5	7	175	9	12	976
6	7	252	10	12	1200
7	8	392	10	14	1400
8	8	512	11	14	1694
9	9	729	12	16	2304
9	10	810	13	16	2704
10	10	1000	14	18	3528
11	10	1210	16	20	5120

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